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COMETS

COMETS

THEIR NATURE, ORIGIN, AND PLACE IN THE SCIENCE OF ASTRONOMY

BY

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AND

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PREFACE

The subject of Comets is of special interest both to students of astronomy and to general readers. The former are drawn to them by the many interesting and perplexing problems presented both by their motions and by their behaviour, the latter by the magnificent appearance that a fine comet presents, also to some extent by the contrast between the wonderful accuracy of prediction that is possible for the other heavenly bodies and the unexpected manner in which comets "swim into our ken." Most of the fine comets have such long periods that they have not been seen since astronomy became an exact science, so that when they come they take us by surprise. Unfortunately, it is many years since a grand comet was visible in our northern skies, so that some of our readers may not have had personal experience of them.

Besides sharing with others in admiration of the aspect of comets, students of cometary orbits have the possibility of other thrills in finding that some new arrival is a long-lost friend. For example, Mr A. F. I. Forbes found a comet in South Africa in November 1928; I deduced an orbit from three early observations, and on

searching through the catalogue I found that there was great similarity with that of the comet found by Coggia and Winnecke in 1873—that comet was already suspected to be the same as one seen by Pons in 1818. Further research proved that the three apparitions all belonged to the same body, which returns every twenty-seven or twenty-eight years. Some similar thrills were afforded by the search into the past history of Halley's comet which was carried out by Dr Cowell and myself, with some other helpers. This proved that the famous comet of 1066, depicted on the Bayeux tapestry, was Halley's comet; this had been already suspected by Dr Hind, but no one had previously suspected the identity of Halley's with the grand comet of August and September 1222, "compared with which the moon appeared as if dead," which our work established.

Miss Mary Proctor is very well qualified to write on comets. She made important observations of Halley's comet when near the earth in 1910, and was one of the first to detect that the tail remained visible in the morning sky after the head had passed to the evening sky; in addition, she is well acquainted with the work of her famous father, Richard A. Proctor, who showed the untenability of the "Capture Theory" of comets, which, unfortunately, is still put forward in many text-books of astronomy. This subject is discussed in the following pages,

which also give an idea of the romance of "comet hunting," and sketches of the careers of some famous comet hunters. This is work in which more helpers would be useful, and I express the hope that the book may stimulate others to join the ranks of the hunters.

ANDREW C. D. CROMMELIN.

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CHAPTER I

WHENCE COME THE COMETS AND WHAT IS THE ORIGIN OF THE COMET FAMILIES OF THE GIANT PLANETS?

THE first query is as yet unanswered satisfactorily, since the verdicts differ widely. Some authorities are of the opinion that comets come from outer space, while others believe that they have been ejected from the sun in the days of its youth, or from the giant planets when they were as yet in the sun-like stage and probably still possessing much heat-energy in their interiors. According to Dr Crommelin, it seems probable that the vast extent of the cometary orbits, which go out to distances about sixty times that of Neptune from the sun, implies one of two things—either that the material forming the solar system was once spread over this huge volume of space, or the tidal disturbance, which the planetesimal hypothesis supposes to have taken place due to

the near approach of another star to the sun, resulted in a distribution of matter over a region much wider than that of the known planetary orbits.

As the sun journeys onwards through space its strong attractive power not only keeps its family of planets subject to its sway but retains the allegiance of myriads of disconnected particles of so light and tenuous a nature that they might well be compared to will-o'-the-wisps compelled to follow in its wake. The first comet that was proved to show full obedience to the law of gravitation was Halley's comet, which exhibited in a remarkable manner the characteristics which distinguish comets from the other heavenly bodies and make them so mysterious to the student of science. Try as they will, comets cannot sever connection with the solar system, to which they are linked by means of the law of gravitation—that invisible bond which prevails throughout the length, breadth, depth, and height of the entire visible universe.

With regard to the solar origin of comets, we can see in the solar prominences eruptions of gas at sufficient velocities to carry some of the projected matter away from the sun. Likewise, an examination of the spectrum of comets and meteors reveals large amounts of hydrogen and its compounds, suggesting their origin in an atmosphere like that of the sun. The solar prominences may be divided into two classes,

the quiescent or diffused and the eruptive or "metallic," so-called since their spectrum shows lines of many metals besides hydrogen. With the former, which are usually immense clouds, often as much as 60,000 miles in height and of corresponding horizontal dimensions, usually found on all portions of the solar disc, or cloud-like forms floating entirely detached from the sun's surface, no possible connection could be traced with comets, since they exist and move only in the solar neighbourhood, just as the clouds do which float in the atmosphere surrounding our planet.

The eruptive prominences, on the other hand, are brilliant and active, reaching at times elevations of 100,000, 200,000, or even 400,000 miles. Most frequently they assume the form of spikes or flames, presenting a great variety of other fantastic shapes. We can see this for ourselves while watching them with the spectro-helioscope, an ingenious instrument devised by Dr George E. Hale of the Mount Wilson Observatory, California. It enables one to see the sun-flames not merely at the limb of the sun but actually on its surface. These solar clouds are most fascinating objects to watch on account of the beauty of their form and the rapidity with which they change in appearance. Portions actually seem to move with a real velocity of at least 250 miles a second, so that it is no exaggeration to refer to such phenomena as veritable "explosions." The only drawback to the theory is

that these eruptions of gas are of insufficient velocity to carry some of the projected matter away from the sun, on which they would fall back at their return.

In an article, July 4, 1884, on "Comet Families of the Giant Planets," by R. A. Proctor, in *Knowledge*, vol. vi., p. 5, he showed himself strongly in favour of the view that the giant planets were the actual parents of the comet families which are attached to them. "There is a large family of comets, every member of which travels in an orbit passing near the orbit of Jupiter; another family, every member of which can be similarly associated with Saturn; others depending in the same way on Uranus; others on Neptune; and, in fact, so fully has this sort of relation been recognised that the idea has even been thrown out that a planet travelling outside the orbit of Neptune, but as yet unknown, might be detected by the movements of a comet intersecting the great plane of planetary movement far beyond Neptune's orbit. It may be mentioned, indeed, in passing, that the comet of 1862 (known as Tuttle's comet), which has been associated with the meteors of August 10 and 11, intersects the plane of planetary movements at a place about as far beyond the orbit of Neptune as that orbit is beyond that of Uranus, and that it has been held probable that at that distance an as yet undiscovered giant planet may travel."

This prediction, which was made by the noted French astronomer, Flammarion, was actually verified in the month of March 1930, by the discovery of the planet Pluto, which is about forty times as far from the sun as our planet, requiring some 250 years to complete its orbital journey round the sun. However, it is too small to be the parent of a comet. Yet it is worth noting that its distance agrees fairly well with one predicted from comets' orbits.

"This remarkable relation among the orbits of the comets which travel periodically around the sun has been interpreted by supposing that all such comets were drawn in from outer space by the sun's attraction, and prevented from returning to outer space by the disturbing influence of one or other of the giant planets. If we suppose a comet, drawn sunwards past the orbit of Jupiter, to be so perturbed by the action of that planet as to lose a considerable portion of its velocity, then that comet would travel thereafter on an orbit passing close to the point on Jupiter's orbit where it had been thus perturbed in such sort as to become an attendant on the sun. But in the first place, the explanation requires that the original orbit of the comet should have passed near the orbit of Jupiter, and a little consideration will show that there should be millions of comets for each thus travelling—a numerical relation not found to exist among the cometic systems. And secondly,

while the explanation would be valid enough were a comet a solid globe or very small, it fails utterly when we recognise that a comet is a flight of bodies occupying a very large extent of space. It can be shown that supposing a comet's head to be but 10,000 miles in diameter and formed of discrete meteoric masses, then if the comet came near enough to Jupiter for its centre to be disturbed in the way the theory requires, those meteoric masses nearest to Jupiter would be so much more disturbed as to be sent on very different orbits, while the new orbits of those masses farthest from Jupiter would be so much less disturbed that their orbits would also be entirely different. The theory that such comets have been introduced from without fails utterly in the presence of observed facts, and would never, indeed, have obtained acceptance for an instant but for the carelessness with which such theories are too often dealt with, being presented as abstract ideas instead of being tested in measure and quantity.

" The existence of the comet families of the giant planets can scarcely be explained without assuming what we have already, in another way, been led to recognise—the ejection from the giant planets of masses of matter in eruptions akin to those which take place in the sun. Whether such eruptions take place now in the giant planets or not would be difficult to prove, for although we have evidence of tremendous dis-

turbances, we have nothing to show conclusively that these would suffice to eject matter for ever from within these globes. Whether a careful study of the region outside the discs of Jupiter and Saturn would reveal aught throwing light on the matter, I am not prepared to say; but I am certain the edges of the discs of the planets are worth much more careful study than they have yet received. Undoubtedly many of the comets of Jupiter's family must have been added to the solar cometic system thousands of years ago.[1]

"But quite possibly both Jupiter and Saturn still eject matter from time to time with such velocities from their interior that it passes away never to return to them. In this, as in many other features, Jupiter and Saturn resemble the sun."[2]

Jupiter has a large family of over fifty comets which seem to owe him allegiance, since, with regard to the Lexell and Brooks's comets, he has been caught in the act of profoundly modifying their orbits. For instance, Lexell's comet, which was discovered in 1770, was supposed to have a period of only five and a half years, in which case the comet should have returned to perihelion in 1776, but it was not seen, though Messier (so keen on capturing comets as to have

[1] We have now witnessed the demise of several short-period comets, and cannot possibly give them more than a few thousand years. A few centuries is more probable.—A. C. D. CROMMELIN.

[2] "Comet Families of Giant Planets." *Knowledge*, vol. vi., p. 5.

been nicknamed " the ferret of comets " by Louis XIV. of France) and others were constantly on the watch. Apparently, in May 1767, the comet had passed very close to Jupiter and had remained exposed to its attractive influence for a considerable time. According to Lexell this had exercised such an effect on what had been the previous orbit of the comet as to transform it into a short-period ellipse, which he found represented the comet's movements in the year 1770. With the materials before him Lexell made the suggestion that the comet might be seen again in the summer of 1781 after again passing under the powerful influence of Jupiter in the summer of 1779. Nevertheless, despite the fact that diligent search was made for it, the comet failed to reappear, and Lexell came to the conclusion that whereas Jupiter had driven the comet in 1767 into the small elliptic orbit, so had it succeeded in driving it out again into a new one which has never been traced.[1]

THE GRIGG-SKJELLERUP COMET

One of the late additions to the Jupiter family is the Comet Grigg-Skjellerup. It was discovered by Mr John Grigg, of Thames, New Zealand, on July 22, 1902. It was a faint comet in the constellation Virgo. Mr Grigg sent a telegram to Melbourne Observatory, but for some reason

[1] See " History of the Comets," p. 87, by G. F. Chambers.

it was delayed, so there are no observations except those made by the discoverer, which are, unfortunately, very rough and extend over twelve days. They were quite inadequate to show the ellipticity, and a parabolic orbit was assumed. It is known as Comet 1902*b*. With regard to his discovery, Mr Grigg wrote as follows: "I was anxious to note its position closely, but there were no stars in the field of view with it, nor could I find a star near it that I could identify. But I found several of nearly the same declination though differing considerably in R.A. As twilight was rapidly coming on, I could not take the necessary time to note the difference of R.A. while the tube remained fixed, but I managed to obtain a difference of declination. I have since computed the effect of refraction on the places of the comet and three stars." (*Note.*—I have endeavoured to identify the stars from the Cape D.M., but without success. The only stars near the place are extremely faint.—A. C. D. CROMMELIN.) [1]

Grigg's comet was rediscovered by Mr Skjellerup at the Cape of Good Hope in May 1922. It was observed for some days by Messrs Crawford and Leuschner, of Berkeley, California, who deduced that it had a short period, and conjectured that it was identical with Grigg's comet of 1902. "Subsequent calculations by Dr G. Merton, utilising some photographic

[1] *Journal B.A.A.*, vol. xiii., p. 169.

observations made at Greenwich two and a half months after the discovery, made the identity almost certain. The comet had completed four revolutions in the interval, its period being five years less eleven days. The comet was seen again in 1927 at about the same time as the Comet Pons-Winnecke. It was also seen in 1932, and is due to reappear in 1937. Its period is the shortest of any known comet, with the exception of Encke's." [1]

March 27, 1927, witnessed the return of the periodic Comet Grigg-Skjellerup (=1927*e*). On that date Mr F. J. Hargreaves at Kingswood (Surrey), using two aeroplane lenses of 20-in. focal length, working at about $F/5\frac{1}{2}$, obtained two photographs, and on them Dr G. Merton detected the very faint image of the comet. The approximate position confirmed by subsequent observations was 1927, March 27. 865 U.T. R.A.=5 hours 46 mins. 59 secs. The comet was within 5′ of the position predicted, and the success of the prediction may be accepted as a further proof of the identity of Grigg's comet 1902 II., with Skjellerup's comet 1922 I.[2]

There is special satisfaction in connection with the Comet Grigg-Skjellerup (=1927*e*) because it is an all-British comet. Mr John Grigg's home was at Thames, New Zealand; Mr J. F. Skjellerup resides at Melbourne,

[1] "Splendour of the Heavens," pp. 428-429.
[2] *R.A.S. Memoirs*, vol. lxiv., Part III., 1927, April 2.

Australia, but was in South Africa when he found it; and Dr G. Merton and Mr F. J. Hargreaves have their homes in England. Moreover, all four are, or were, members of the British Astronomical Association. Mr Skjellerup is an enthusiast in connection with comets, keeping an ever watchful eye on the sky, endeavouring to cover all he can reach once a month. Comet 1927*k* (Skjellerup) was another of his finds. At discovery it was not many degrees away from the sun, but was clearly visible to the naked eye. In the telescope it showed a tail about 3° long. Being a bright comet there were many confirmations of his discovery. Captain Cameron-Swan, who observed it on December 8, wrote as follows concerning this comet:

"It was clearly visible to the naked eye. Seen through the telescope (3-in. reflector, focal length 40) it presented a beautiful appearance, having a bright and clearly defined nucleus and a long straight tail which more than filled the field of view. Later it increased greatly in brightness, and was seen by several observers in full daylight with the naked eye. Spectroscopic and radiometric measurements were secured in full daylight on December 16." [1]

In connection with Brooks's comet 1889 V. which has had its orbit greatly modified by the giant planet Jupiter: up to 1886 it had an

[1] *R.A.S. Memoirs*, vol. lxiv., Part III., 1927, April 2.

orbit requiring twenty-seven years for the comet to complete its journey round the sun, while in 1889 it was found to be moving in an orbit of seven years. The idea that certain comets are associated with particular planets, or, to put it in another way, that planets have certain groups of comets attached to them, was suggested by Laplace, who was of the opinion that such comets had been " perturbed " by the planets.

A large family of comets has obvious connection with Jupiter, though in my father's view the connection is not one of " capture," but of expulsion. The following are members of the family: Encke, Pons-Winnecke, Tempel I., Tempel II., D'Arrest, Tempel-Swift, Faye, Brorsen, and many others. Like flies in a spider's web they all lie enmeshed in the over-powering attraction of the giant planet. Saturn has at least three comets, to which must be added the remarkable comet found by Neujmin on September 6, 1913, which has a period of eighteen years. Its appearance was unusual, for frequently it showed no nebulosity and looked exactly like an asteroid. However, on September 24, it developed a fan-shaped tail, which was photographed at Heidelberg. It is doubtful whether the Schwassmann-Wachmann [1] and

[1] The remarkable Comet Schwassmann-Wachmann I., perihelion in 1925, but not found till 1927, and observed every year since then. It has a small eccentricity, and is the only comet that is visible round its whole orbit, which lies entirely between those of Jupiter and Saturn. —A. C. D. CROMMELIN.

Gale's last comet should rank as comets belonging to the Jupiter or Saturn group since they are between the two groups. Saturn's comet group is mainly of interest on account of the inclusion of Tuttle's comet, which was discovered by Méchain on January 9, 1790. It was closely observed for two weeks, but on January 11, Messier could see only a nebulous patch without any indication of a nucleus. It was not observed again until its return on January 4, 1858, when it was rediscovered by H. P. Tuttle at Harvard Observatory, Cambridge, U.S.A., when it passed its perihelion on February 23. It was then found to be a periodical comet with a period of about thirteen and a half years. It was again seen in November 1871, August 1885, May 1899, October 1912, and April 1926.

There are nine comets whose orbits are associated with that of Neptune. The list includes the comet 1852 IV., Westphal; comet 1812 I., Pons; comet 1846 IV., Di Vico; comet 1815 I., Olbers; comet 1847 V., Brorsen; and Halley's famous comet. Four of these have been observed in two or more revolutions, one being Halley's comet which has been traced back with tolerable certainty to 240 B.C., and with some probability to 467 B.C. We have to go back to a very remote period to find a time when Neptune could have exerted considerable influence on Halley's comet. At present there

is no near approach of their orbits and the influence is very slight. Toscanelli, in 1456, was the only man to make sufficiently good observations of the comet of that year (which we now know to be Halley's) to enable an orbit to be deduced. Halley himself felt pretty sure that it was his comet but not knowing of Toscanelli's observations, he was unable to deduce an orbit.

Paolo Toscanelli (1397-1482) was a Florentine cosmographer who lived about the middle of the fifteenth century. He designed, in 1468, the famous gnomon in the Florence Cathedral with the express purpose of demonstrating the variation of the obliquity of the ecliptic. This was placed in the vast dome of the cathedral, which had been erected to commemorate the festival of San Giovanni, the patron saint of their city. The dome, over 130 ft. in diameter and with its lantern over 387 ft. high, is undoubtedly the most stupendous astronomical instrument for determining the summer solstice that the world possesses.[1] "It is impossible to say whether Toscanelli was primarily concerned with the variation of the obliquity of the ecliptic. He certainly obtained with the gnomon a far more accurate reading of the then existing figure of 23° 30′ for the obliquity than did either Purbach or Regiomontanus, and it must have represented a fairly accurate astronomical instrument before

[1] W. A. Parr, *Knowledge*, December 1905.

the introduction of the transit instrument by Olaus Roemer in 1670."[1]

(In 1474 we find Columbus expounding his views to Paolo Toscanelli, the Florentine physician and cosmographer. In 1470 Columbus, after reading about the travels of Marco Polo and Mandeville, came to the conclusion that much of the world remained undiscovered, and step by step to have conceived that design of reaching Asia by sailing west, which was to result in the discovery of America. *Ency. Brit.*, vol. vi., 9th edition, p. 171.)

[1] *B.A.A. Journal*, vol. xl., p. 297, July 1930.

CHAPTER II

PONS, FAMOUS COMET HUNTER

By A. C. D. Crommelin

PONS (Jean Louis), 1761-1831, French astronomer, born at Peyre (Haut Dauphine), was famous as a comet hunter. Dr A. C. D. Crommelin going through Galle's "Cometenbahnen," finds Pons's exact record, which he makes thirty-six. Many of them were discovered independently by others; but in those days communication was so slow without telegrams or trains that full credit is given to both discoverers :—

1801, Pons, also Méchain and Bouvard.
1802, Pons, also Méchain.
1804, Pons, also Bouvard.
1805, Pons (comet now called Encke's).
1806 I., Pons (now called Biela's).
1806 II., Pons.
1808 I., Pons.
1808 II., Pons.
Pons found three other faint comets in 1808; too few observations to get orbits.
1810, Pons.
1811 II., Pons.
1812, Pons (now called Pons-Brooks).
1813 I., Pons.
1813 II., Pons.

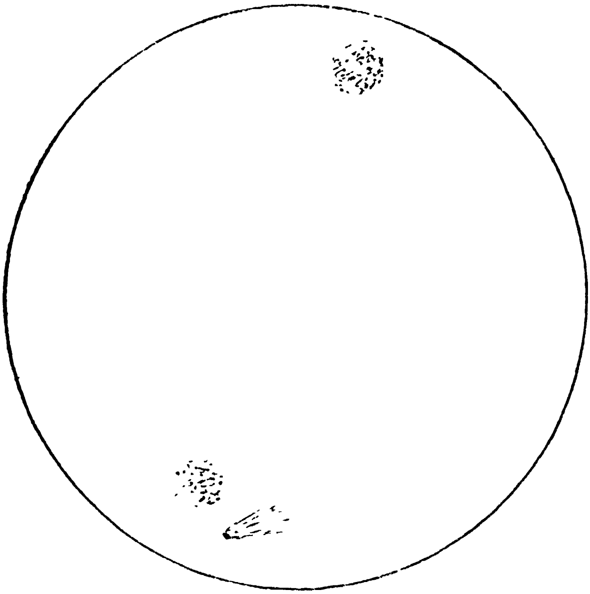
1816, Pons.
1818 I., Pons (now called Pons-Coggia-Winnecke-Forbes).
1818 II., Pons.
1818 III., Pons.
1819 I., Pons again discovered comet now called Encke's.
1819 III., Pons (now called Pons-Winnecke).
1819 IV., Blanpain first discoverer, Pons second.
1821, Pons first, Nicolet second.
1822 I., Gambart first, Pons second.
1822 III., Pons.
1822 IV., Pons first, Gambart second.
1824 II., Scheithauer first, Pons second.
1825 II., Pons first, Harding second.
1825 IV., Pons first, Biela second.
1826 II., Pons.
1826 IV., Pons first, Gambart second.
1826 V., Pons first, Clausen second.
1827 I., Pons.
1827 II., Pons first, Gambart second.
1827 III., Pons.

Messier, Brooks, Barnard, Swift, Perrine, Tebbutt, etc., also made many discoveries, but none rivalled Pons. They "also ran" compared with him. Although Pons was so great at detecting comets, his descriptions of their positions were vague. He seems to have been unable to make exact measures, which is unfortunate, more especially in the case of comets that he alone observed, notably 1818 I.

PONS'S COMET OBSERVATIONS

It is difficult to find exact particulars of the instrument used by Pons in making his observa-

tions of comets; a note by him, published in *Astronomische Nachrichten*, vol. vii., p. 113, 1829, gives a little information. It also contains a



Sketch made by Pons of a Comet seen at 5 A.M. on February 9, 1808.

The nebulæ are Messier X. and XII., in Ophiuchus.

[*From "Astr. Nach.," vol. vii.*

sketch made by him at 5 A.M. on February 9, 1808, showing a faint comet[1] in the field of view with two nebulæ in Ophiuchus, which have been identified as Messier XII. and Messier X. The distance between them is $3^\circ\ 17'$, so that if

[1] A copy of this sketch is here reproduced.

the drawing represents the field of view correctly this would be $4\frac{1}{4}°$ in diameter. Pons, however, states that the field of the "Grand Chercheur" is very nearly 3° ; if so, the sketch shows more than he would see at once. In any case, it was a very large field, and the telescope was evidently one of short focus and low power, specially designed for comet observation. The comet in the sketch was not sufficiently observed to determine its orbit ; some have suspected that it may be Comet Pons-Winnecke, discovered by Pons eleven years later, on June 12, 1819 ; this, however, is very uncertain. The comet was sufficiently observed in 1819 to determine its period as about five and a half years ; it was, however, not seen again till 1858, when Winnecke found it and proved its identity with the object of 1819. For many years it was simply called Winnecke's comet, till Mr Denning pointed out that this did not render justice to Pons, the original discoverer ; so that since then the double designation has been generally used, except in Germany.

Comet Pons-Winnecke is interesting from the notable changes that have taken place in its orbit since 1819 ; both the period and the distance from the sun at nearest approach have increased. In 1819 the latter distance was 72,000,000 miles ; in 1898 it was 86,000,000 ; in 1915 it reached the orbit of the earth. As a result of this approach to us there was a meteoric

display from meteors following the comet on June 28, 1916, the radiant point being in Draco. Mr Denning and Professor Olivier independently detected their connection with the comet. It was the only time that these meteors met the earth, as the rapid outward movement of the orbit quickly took them out of the earth's path. We may contrast this short-lived shower with the Perseids and Leonids, which have given meteoric displays for centuries. A great meteor fell in Siberia on June 30, 1908, which some people thought might belong to the Pons-Winnecke stream ; but further examination showed that the meteor was travelling from south to north, which disproved its connection with this comet. At the comet's return in 1921, its orbit was some 3,000,000 miles outside that of the earth ; since there was no approach to Jupiter between that and 1927, the distance of the orbit from ours was unchanged. In 1927, the comet approached the earth within 3,500,000 miles, which is, with one exception, the closest approach on record. Advantage was taken of it to study the comet's nucleus, which proved to be small and stellar, not more than a mile or two in diameter.

(*N.B.*—A copy is here given of Monsieur Baldet's sketch of the aspect of the comet at its near approach. The dots do not indicate separate points of light, but denote luminous vapour, bright where the dots come thickly, and faint where they are thinly scattered. The scale

of the sketch is from the measure of $5''$ of arc at the bottom. The disc of Jupiter would cover several slides from the same scale. The surprise was the small nucleus of the comet; it was only a mile or two in diameter. This was confirmed by observations in America. I think that Baldet made the discovery with the great Meudon refractor.)—A. C. D. CROMMELIN.

The closest approach was that of Lexell's comet on July 1, 1770, the distance being 1,500,000 miles. But that comet had just been discovered and people did not know how near it was till it had passed away.

Between 1927 and 1933 the orbit of Pons-Winnecke moved out 6,000,000 miles more, so that there will be no more close approaches to the earth. Its period is now almost exactly half that of Jupiter, and every twelve years it makes close approaches to that planet, which give rise to these large changes in its orbit. Its next return is in June 1939 when its orbit will be almost the same as in 1933. Curiously enough another comet approached the earth within 5,000,000 miles in June 1930; this was Comet Schwassmann-Wachmann (3), its orbit being similar to that of Pons-Winnecke, and it is conjectured that they once formed a single comet which split in two at some date in the past.

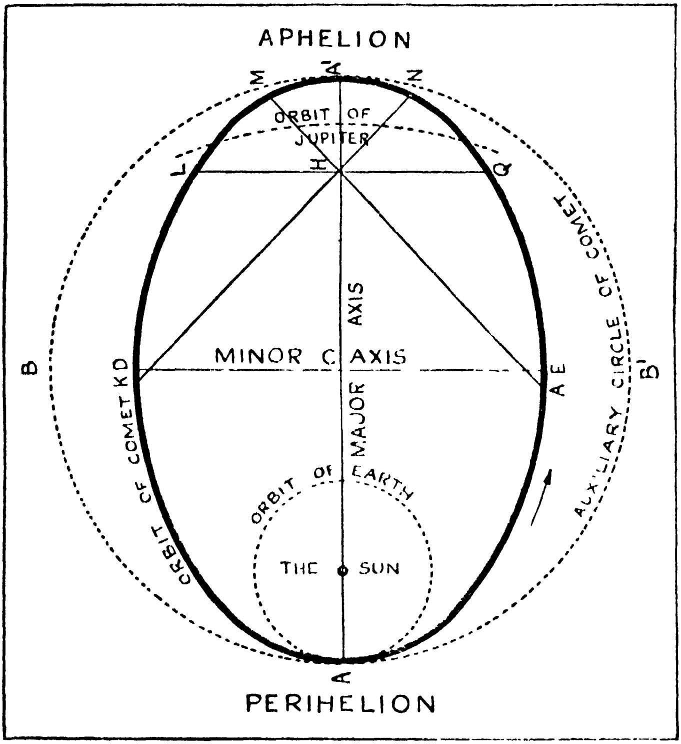
THE ELLIPSE

By A. C. D. Crommelin

The Ellipse is familiar to all under the name of "Oval." Any circular object, such as a coin, when viewed obliquely appears as an ellipse. To draw the elliptical orbit of Comet Pons-Winnecke we proceed as follows: The half-major axis of its orbit is 3·305, the unit being the earth's distance from the sun. We draw a circle ABA′B′ with radius 3·305; the eccentricity is 0·6856. Multiply this by 3·305, and we get 2·266, which is the distance of the sun from the centre. We insert the sun S on the major axis, and also the "Empty Focus" H, on the other side of C. Draw circles with centres S, H and the radius 3·305, the same as that of the first circle. These two circles cut each other at D, E, the ends of the minor axis. Now imagine the first circle tilted so that B comes vertically above D, and B′ below E; then other points on the ellipse are given, being below or above points on the circle. This is the same thing as saying that a circle viewed on the slant appears as an ellipse.

One other point: Draw the lines HK, HL, HM, etc., each making angles of 45° with each other; then the times taken for the comet to move from A to R, from R to Q, from Q to N, from N to A′, and so on, are all nearly equal,

each being one-eighth of the time round the orbit ; each is about nine months in the case of this comet. This simple method is almost exact



The Orbit of Pons-Winnecke.

for the planets, and even in such an eccentric orbit as this it is fairly near the truth. We may express it thus : " The angular motion round the Empty Focus is nearly uniform." A portion

of Jupiter's orbit, also that of the earth, are shown by the dotted curves.

ELLIPTICAL MOTION : Kepler's second law states that equal areas about the sun are swept out in equal times. It follows that when near the sun the comet or planet moves rapidly, when far away, slowly : for the daily area is roughly proportional to distance travelled multiplied by distance from sun, so when one is large the other is small.

FOCUS, singular of FOCI, of an ELLIPSE : The foci of an ellipse are two points on the long or major axis of an ellipse, both being an equal distance from the centre. The sum of the distances from any point on the ellipse to the two foci is equal to the major axis.

ECCENTRICITY OF AN ORBIT : If an orbit is elliptical, its eccentricity or deviation from the centre is the distance between the centre of the ellipse and its focus. In the case of an orbit of a comet, it is the distance between the centre of its orbit and the centre of the sun, which is the focus. In each case the half-major axis of the orbit is the unit in which the distance from centre to focus is to be measured.

ORBIT (from Latin, *orbis*, a ring) : The path of a celestial body round its primary or round a common centre of gravity.

PERIHELION (Gr. *peri*, near ; *helios*, the sun) : The point in the orbit of a comet which is nearest to the sun.

APHELION (Gr. *apo*, away from ; *helios*, the sun) : The most remote point of a comet's orbit from the sun.

MAJOR and MINOR AXIS : The long and short axes of an ellipse.

CHAPTER III

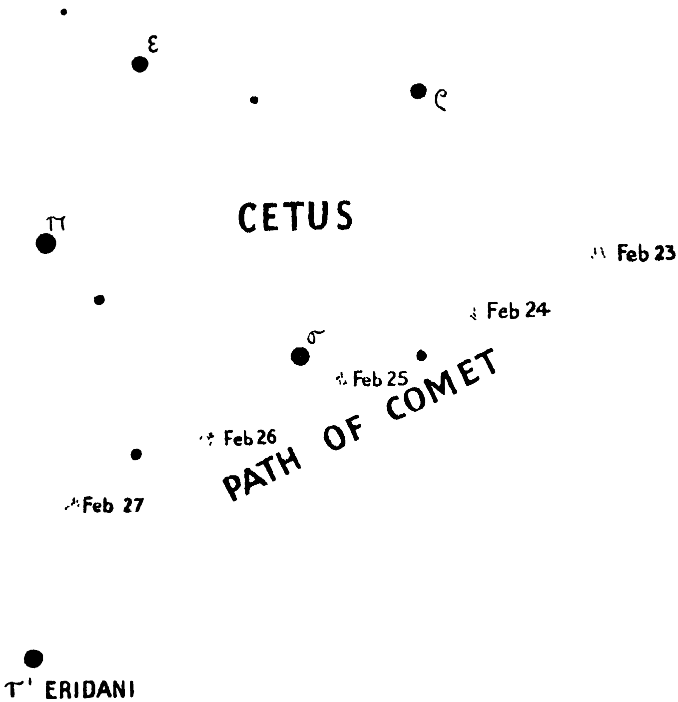
COMET PONS-COGGIA-WINNECKE-FORBES

By A. C. D. Crommelin

THIS comet has a curious history, its true orbit not being known till 110 years after its first discovery. It was one of the numerous comets found by Pons at Marseilles. He was the only person to see it at that apparition, and it is worth while to give in full the account that he sent to Professor von Zach for publication in his *Astronomical Zeitschrift* for 1818:

"On February 23, 1818, at 7 P.M., Herr Pons discovered a comet on the breast of the Whale, in south declination 15° 15′; he describes it thus: 'This comet is about the same magnitude as that last mentioned; it is invisible to the naked eye, and it bears no illumination of the field. It has neither tail nor beard; its middle point is slightly brighter, the nebulosity little condensed. On February 24, I only obtained a few glimpses owing to bad weather; I recognised, however, that it has fairly rapid

motion, travelling $1\frac{3}{4}°$ daily towards the east, 40′ towards the south. On February 26, it



The Path of Comet Pons-Coggia-Winnecke-Forbes at its Discovery in Cetus, February 1818.

crossed the field of the equatorial three minutes of time after a star of the 4th magnitude; this star is the most southerly of the four that

form a quadrilateral on the breast of the Whale (*i.e.*, it was Sigma Ceti). On February 27, the comet was in the field of the telescope with a star under the foot of the Whale, some 50′ to the east. About a fortnight ago I saw a faint nebulous spot a few degrees under the star B of the Whale, which bad weather prevented me from seeing again ; I conjecture that this was the comet. In view of its motion, it will soon pass below our horizon.' "

No one else saw the comet at that apparition, and Pons's observations were too rough to give trustworthy information about the orbit ; attempts were made that we now know were not very far from the truth. The above paragraph illustrates the fact that though Pons had great skill in detecting comets, his sight being very acute, his power of determining their position was small ; his measures and estimates were rough, and he often failed to record details. Controversy arose about Pons's sketch of February 9, 1808.[1] Pons said that it was "reversed," but this might either mean reversed from the naked eye aspect, or reversed from the telescopic appearance. It makes a difference of 4° in the comet's position according as north is taken to be at the top or the bottom. The direction of the tail, since the drawing was made before sunrise, would indicate that east was to the left

[1] This may have been Pons-Winnecke, but more likely was another comet. (See sketch on p. 18.)

and north at the top; but supporters of the other view did not trust Pons's drawing of the tail as correct.

The next stage in the history of our comet was in the autumn of 1873. A comet was independently picked up by Winnecke in Germany, and Coggia in Marseilles (who discovered a very bright comet in 1874). This comet was well observed in Europe for six days, a period long enough to give some of the elements of the orbit with precision, but too short to determine the comet's time of revolution, which is the most difficult to find of all the elements. Several astronomers conjectured that it was Pons's comet of February 1818. Of these, Schulhof made the most exhaustive researches, and he made the identity nearly certain, but could not say how many revolutions the comet had completed in the intervening fifty-five years. We now know that it had been twice round, but Schulhof preferred a shorter period.

The question remained undecided until Mr A. F. I. Forbes discovered a comet from his observatory at Blairythan, Hermanus, Cape of Good Hope, on November 19, 1928. It was his first discovery, but he has since made several others. Three observations were soon available, and preliminary parabolic elements were deduced by Dr Smiley in U.S.A., by Mr Wood at Johannesburg, and by A. C. D. Crommelin. All three computers searched the catalogue of comets and

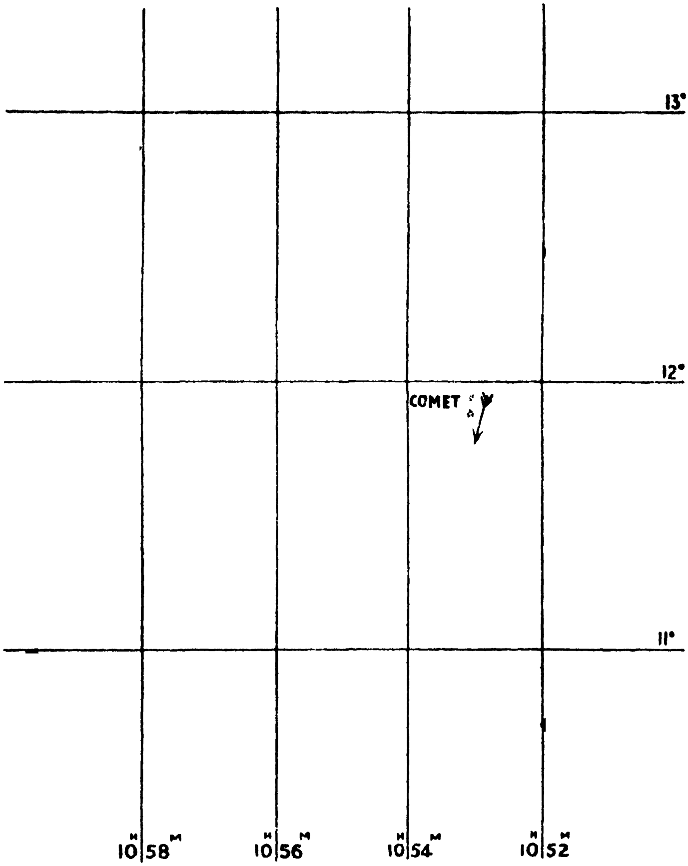
noted the resemblance of the orbit to that of Coggia-Winnecke in 1873, and as the interval from 1873 to 1928 was about the same as that from 1818 to 1873 (actually they differed by eleven months), they all felt assured that the three apparitions belonged to the same comet. The question still remained as to how many revolutions it had made in each interval? When the comet had been observed for ten days, attempts were made to get the period directly from the observations. The first attempts suggested that the comet had taken about fifty-five years to go round once, but by the end of three weeks this period was seen to be too long, and it was evident that the true period was about twenty-eight years. In that case four revolutions of the comet had been accomplished since Pons observed it in 1818. An enigma was thus solved that had been worrying computers since 1873. Before making a final decision on identity, it was necessary to determine whether the perturbations by the large planets would explain the fact that the interval from 1818, February, to 1873, November, was 55 years 10 months, while that from 1873, December, to 1928, November, was 54 years 11 months. This point was examined by Dr Crommelin in *Monthly Notices of R.A.S.* for April 1929. The perturbations were shown to be of almost exactly the required amount, thus rendering it certain that the apparitions of 1818, 1873, 1928 belonged to

a single comet, which had returned unobserved in 1845 and 1901.

When the orbit of the comet was known, the track of the comet before its discovery in 1928 was calculated (see Chart). Monsieur Quénisset of the Juvisy Observatory, the discoverer of a comet in 1893, then examined two photographs which he had taken in Switzerland early on October 25, 1928, in connection with the study he was making of the Zodiacal Light. He found an image of the comet on each of the photographs,[1] and its identity was made certain by the fact that it had moved by the calculated amount between the two exposures. The scale was small, but as they were nearly a month before other observations had been obtained they were useful for improving the period of the comet. Dr Crommelin deduced this as 27·901 years from the observations, and 27·913 years from the calculated perturbations, a practically perfect agreement. The comet was glimpsed by Mr Yamasaki in Japan on October 26, but as he made no announcement till many days later he lost his chance of having his name attached to the comet. Prompt announcement is one of the necessary conditions for this recognition.

[1] Quénisset's photographs of Comet Pons-Coggia-Winnecke-Forbes, October 25, 1928. The drawing shows on an enlarged scale the two images of the comet; the mean times of the two exposures were 3.42 and 4.12 A.M. The Right Ascension and Declination are for 1855. The region is in Leo, 13° east of Regulus. The brightest star is of magnitude 6·5. The comet moved 3′ to the south-east between the exposures.

It is of interest to give some particulars as to the situation of the orbit of this interesting comet.



Comet Pons-Coggia-Winnecke-Forbes.

1928, Oct., 25d. 3h. 42m. a.m. Upper Image.
1928, Oct., 25d. 4h. 12m. a.m. Lower Image.

[*Photographed by Quénisset.*

Its nearest approach to the sun is 69,000,000 miles ; at that point it is only 4,000,000 miles from. the orbit of Venus. The comet will make a near approach to Venus at the return in October 1956, which will have a small but appreciable effect on its orbit. It does not approach the earth's orbit nearer than 20,000,000 miles, the distance at which it was in 1873. The inclination of the orbit is 29°, which prevents the comet from making very close approaches to Jupiter or Saturn. It did not approach either planet nearer than 250,000,000 miles during the whole period from 1818, so that the orbit has not suffered violent changes. When farthest from the sun the distance is 1,641,000,000 miles, or 149,000,000 miles inside the orbit of Uranus, so the comet may be considered as belonging to the family of Uranus in company with Tempel's comet of the Leonid meteors. It happens that the comet goes round almost exactly three times while Uranus goes round once. Thus, the conditions nearly repeat themselves after eighty-three years, the sidereal period of Uranus being eighty-four years. At present there are no approaches to Uranus nearer than 900,000,000 miles. In fact, we should need to go back a thousand years to find a near approach.

In his researches in connection with this comet, Schulhof noted that it might be identical with a comet observed by Toscanelli in January

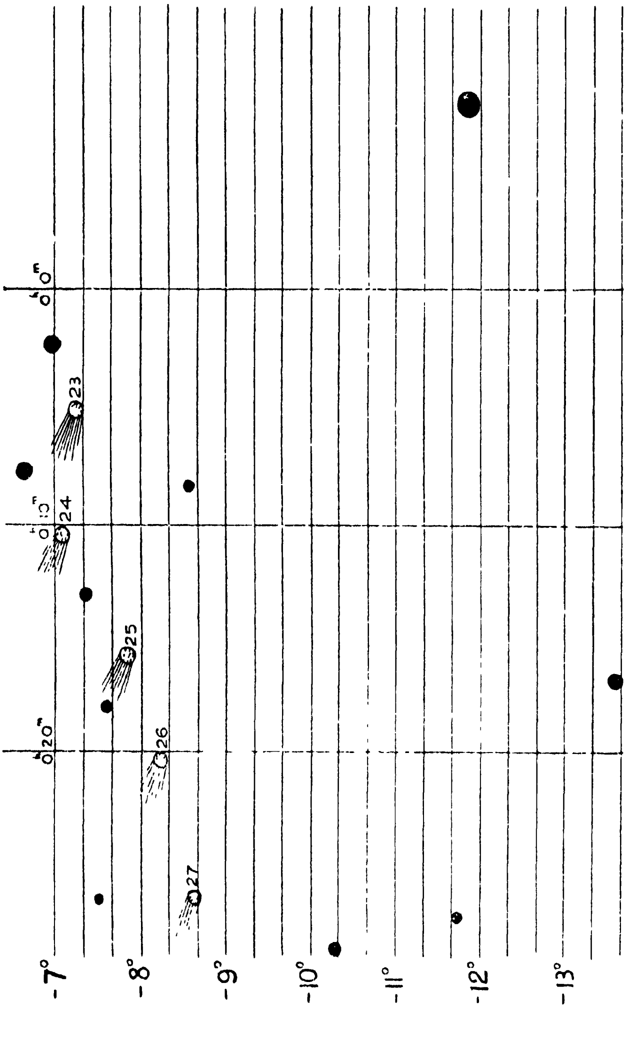


Diagram based on Toscanelli's Sketch, showing the Motion of the Comet from January 23 to 27, 1457.

1457. Toscanelli[1] had been the only person to make observations of Halley's comet in 1456 of sufficient accuracy to use for computation of the orbit. Halley did not know of these observations or he would certainly have included this apparition in addition to the three following ones, from which he made his epoch-making discovery. Toscanelli's observations in January 1457 were not actual measures, but positions of the comet and the neighbouring stars plotted on a diagram. This diagram appears to have remained unknown to astronomers till Professor Celoria discovered it in the last century and deduced therefrom the positions of the comet. He deduced an orbit from the positions without having any idea of a possible connection with any other comet. Schulhof noticed, however, that they bore a very strong resemblance to those which he had lately found for the 1873 apparition of our comet, the only discordance being the inclination of the orbit, which was smaller in Celoria's orbit than in that determined by Schulhof, but as the comet was near the ecliptic, the inclination was rather difficult to find. Another reason for inferring identity is the fact that the interval between perihelion passage in 1457 and 1818 is thirteen times 27·77 years, while the mean period from the modern observations is 27·73 years.

The comet of 1457 was also observed in

[1] See Chapter II. for account of Toscanelli.

China, concerning which the following details are taken from *Chinese Observations of Comets*, by Williams, correcting an apparent mistake of his. He took the *Peih* that is in the Taurus region, when evidently he should have taken the one in the Pegasus region. Dr Crommelin turns the dating into Western reckoning: "In 1457, January 14, another comet was seen in stellar division *Peih* (that is, the region of Gamma Pegasi and Alpha Andromedæ). It was half a degree in length, going to the south-east, gradually lengthening until January 23, when it disappeared." Toscanelli's drawings also show a tail half a degree in length. An attempt has been made to reproduce his diagram from the details given by Schulhof. As we have already seen, Paolo Toscanelli was a mathematician and geographer of some eminence, as well as interested in the projected exploration of the western ocean, for which he constructed a chart which Christopher Columbus took with him on his first voyage. Toscanelli made estimates of the obliquity of the ecliptic. In judging his chart we should remember that it was made long before the invention of the telescope, and that accurate positions of stars were not available. Though his chart is rough, we are greatly indebted for it, since it has enabled us to carry back the story of this comet for many centuries.

There is still another case of a comet that

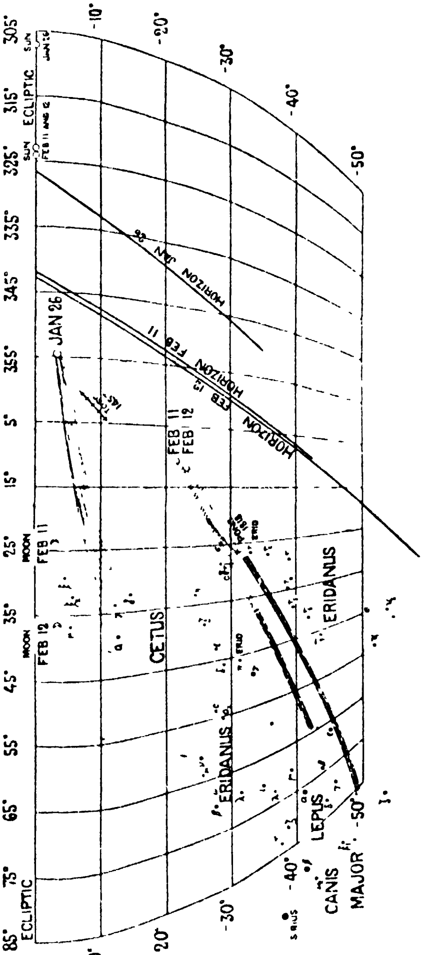


Diagram of the Motion of the Comet of 1625, possibly Comet Pons-Coggia-Winnecke-Forbes.

[*Reproduced by permission from "Journal of British Astronomical Association,"* 1924.

is probably identical with the Pons-Coggia-Winnecke-Forbes. In this case the identification would not have been made without the help afforded by Toscanelli's observations in 1457. But the apparitions of 1457 and 1818 have now been connected by approximate calculation of the perturbations in the interim. This calculation indicates a return of the comet early in 1625. Now Kepler's astronomical diaries contain a record of a comet that fits so well with the calculation that there is little doubt that it is the same. Kepler's record remained unnoticed till early in the last century, when it was published in *Astronomischen Nachrichten*, vol. ii. It was reprinted in the original Latin in the *Journal of the British Astronomical Association*, vol. xliv., No. 6. The following is a translation: "A comet was observed in Austria, towards the south, in January 1625. Of skilled observers of it I only know of Schickard, Professor at Tübingen, who observed it on January 26, in the evening, towards the west, with a long tail stretching from the west towards the east, slightly upwards. It seems to have been retrogradely moving to meet the sun in Capricornus, a constellation with baleful influence to Saxony and to Upper Austria. Schickard saw the comet's tail on February 11 and 12; on the 11th it was short, crossing Eridanus towards Lepus. It went from longitude 38°, south latitude 33°, to longitude 65°, south latitude 43°. On the 12th it was longer,

and farther south from the bend in Eridanus under the centre of Cetus, under the whole of Lepus, towards the back of Canis Major. The head of the comet was hidden by horizontal clouds; therefore it was retrograde, moving towards the sun, since on the following days it was no more seen." (End of Kepler's narrative.) There is one point in this narrative that is obviously wrong. If the diagram in the *B.A.A. Journal*, vol. xliv., No. 10, is reproduced, it is only necessary to refer to it to see that if the comet's head was towards the west in the evening on January 26, as the narrative clearly states, then the observers of the comet must have been in error when they said that the comet's motion was retrograde—that is, towards the right in the diagram—for that would have put the head below the horizon on February 11 and 12, in which case the tail on those days could not have been in the positions indicated. The narrative then requires direct motion, and that accords with the identity of the comet with that of Comet Pons-Coggia-Winnecke-Forbes. The comet was nearest the sun on January 30. Some question arose as to whether Kepler was using old or new style in the account of this comet. It is clear that he was using new style, since that was usual in Austria, where he then resided. In his ephemerides of that period he gives the dates by both styles in parallel columns, but showed obvious preference to new style,

using it alone in eclipse predictions. Moreover, the moon was full on February 12, old style, and it is quite improbable that such a long tail could have been seen in the moonlight.

Another difficulty that may be raised about identity with the Pons-Coggia-Winnecke-Forbes comet is that on no other occasion had that comet a tail longer than half a degree, while the tail of the comet in 1625 was very long. But the behaviour of comets as regards brightness and length of tail is so capricious that the unexpected often happens. Thus D'Arrest's comet was looked for in September 1923, when it should have been at its brightest, but it was invisible. Then it mysteriously brightened up two months later, when Mr Reid accidentally picked it up in his search for new comets.

In this connection we may mention that there are grounds for suspecting that sunspot activity also induces activity in comets that happen to be near. The remarkable formation of the tails of the great comet of 1882, and of Morehouse in 1908, were both at times of solar activity. Now Galileo's sunspot observations show that 1625 was a year of remarkable activity, which might lead to sympathetic activity in the comet's tail. In this connection it is apropos to quote from R. A. Proctor's "Chance and Luck." On page 195 he quotes from De Morgan's "Budget of Paradoxes" as follows: "The late Baron Zach received a letter from

Pons complaining that for a certain period he had found no comets, though he had searched diligently. Zach, a man of much sly humour, told him that no spots had been seen on the sun, and assured him that when the spots came back the comets would come with them. Some time after he got a letter from Pons, who informed him that he was quite right ; very large spots had appeared on the sun, and he found a comet very shortly afterwards." But what von Zach and De Morgan treated as a joke may be actually true. It is, moreover, quite reasonable that the association between sunspots and auroræ may be explained by the theory that excited regions of the sun emit streams of electrons. When these streams meet the earth they produce auroræ and magnetic storms ; while when they meet comets (remembering that comets' tails are due to solar action) we should not be surprised that they produce unwonted activity in the tail.

If the identity of the comets of 1457 and 1625 with Pons-Coggia-Winnecke-Forbes is established, that comet takes second place to Halley's as regards a long historical record, having been seen at five apparitions, extending over an interval of 471 years. It may be objected that Tempel's comet has a record of 500 years between 1366 and 1866 ; but that is a lost comet, since efforts to find it in 1899 and 1933 were of no avail, whereas the orbit of the other is so well known that it should be recovered without

difficulty in 1956, and at subsequent returns. In the attempts which have been made to find further apparitions in the past, hopes were raised regarding comets seen in 1569 and in 1708, but on examining the perturbations the dates were not found to fit.

CHAPTER IV

THE STORY OF HALLEY'S COMET

THE story of Halley's comet appeals to us not only from an historical standpoint but from the fact that it has enabled us to trace—step by step, as it were—the path of one of these seemingly mysterious visitants coming we knew not whence, going we knew not whither. No wonder comets aroused feelings of terror and dismay in the minds of men, especially when it was assumed that they came so near to our planet as possibly to penetrate within its atmosphere, so that they were naturally associated with war, famine, the downfall of monarchies, and universal distress for the inhabitants of the earth.

Pliny, when referring to the comet of 48 B.C., observes: "We have in the war between Cæsar and Pompey an example of the terrible effects which follow the apparition of a comet. . . . That fearful star which overthrows the powers of the earth, showed its terrible locks." The comet of A.D. 79 is said to have preceded the death of the Roman Emperor Vespasian.

But no records of disastrous events associated

with a comet have been so remarkable as those in connection with Halley's famous comet. When it was seen in China and Rome, A.D. 218, April 6, it was described as presenting the appearance of "a fearful, flaming star," which preceded the death of Emperor Macrinus. It was again seen by observers in China and Rome, A.D. 451, July 3, on which occasion it preceded the death of Attila. On November 26, A.D. 684, when it was seen in China and Rome, a drawing made at Nuremburg gives some idea of the popular ideas in those days with regard to the appearance of comets. A.D. 837, February 25, the comet was seen in China and Europe, and preceded the death of Louis le Debonnaire.

However, the best-known reappearance of Halley's comet, when it was seen in Europe and China, occurred A.D. 1066, March 25, when it was regarded in Europe as a warning of the conquest of England by William, Duke of Normandy.

A monk of Malmesbury, seeing his country in danger of invasion—on the one side by Harold, King of Norway, on the other side by William—and concluding that blood would be shed, addressed the comet thus: "I see you then, origin of the tears of many mothers; I have seen you for long, but now you appear more terrible; you threaten my country with entire ruin."

Queen Matilda vividly portrayed the event

on the famous Bayeux tapestry, a copy of which is to be seen in the Victoria and Albert Museum, South Kensington, and the Chapter Room of Westminster Abbey. A group of Normans are shown pointing to the comet, which is adorned with a long flaming tail and the legend : " Isti mirantur stellam." In the adjoining section a messenger is depicted announcing the fatal news to Harold regarding the comet which has suddenly blazed out in the sky, and the coming of the Norsemen whose ships are shown below. Harold seems to be overcome at the combination of misfortune and appears to totter on his throne. William, on the contrary, apparently regards the comet as a good sign, since they appear only " when a kingdom wanted a king ! " [1]

The apparition of Halley's comet in 1066 was discovered in China on April 2, when it was a morning object in Pegasus, and rapidly approaching the sun, which it passed about a fortnight later, becoming an evening object about April 24 (a week after Easter). It was then first seen in Europe, and is described as a star without rays, resembling a white cloud, 3° in diameter. It must then have been very brilliant, being close to the earth. It traversed the constellations of Gemini, Cancer, and Hydra, being finally

[1] " This extraordinary piece of needlework, for such it is, though called a tapestry, is now preserved in the Hotel of the Prefecture at Bayeux, coiled round a machine like that which lets down the buckets of a well, and is exhibited by being drawn out at leisure over a table " (*Penny Cyclopædia*), and is said to have been the work of English damsels retained in the Court of Matilda, the Conqueror's wife.

lost to view in Crater after a period of visibility of about two months.

At its return in A.D. 1456, when Halley's comet appeared early in the month of June, being visible in Europe and China, Europe was once more in a state of great excitement. Constantinople had recently fallen into the hands of the Turks, who were now besieging Belgrade under Mahomet II., and it was feared that if it fell nothing could resist their victorious onslaught. The two opposing armies were resting from their conflict on the night of June 8, while darkness was falling on the earth. Suddenly a sentry was filled with alarm at the appearance in the sky of a comet, " with a long tail like that of a dragon " spreading over two constellations and apparently advancing towards the moon. His fears were intensified as a dark shadow hid the light of the moon from view.

According to the account given by the historian Pontanus : " Some persons seeing the darkness of the eclipse, and perceiving the comet in the form of a long sword advancing from the west and approaching the moon, thought that it presaged that the Christian inhabitants of the West would come to an agreement to march against the Turks, overcoming the enemy. While the Turks, on their part, taking into consideration the state of affairs, fell into no small fears and entered into serious arguments as to the Will of Allah."

One writer, Platina, said that the most learned men of the day predicted that the comet would produce pestilence, the idea at that time being that comets were noxious vapours in the upper regions of the air. In the year A.D. 1531, August, occurred the first return of the comet which was discussed by Halley as well as its second return, A.D. 1607, October, when it was again visible in Europe. At its return, A.D. 1682, September, its periodicity was discovered, and when it was seen all over the world, A.D. 1759, March, Halley's prediction that the comet would return that year was fulfilled.

"It was the first periodic comet whose return was predicted, Halley basing his prediction upon the fact that he found its orbit in 1682 to be nearly identical with those of the comets of 1607 and 1531, which had been carefully observed by Kepler and Apian; and he also found records of the appearance of a bright comet at a similar interval in 1456. He attempted to go further back, but all his identifications before 1456 are now known to be wrong. He noticed, of course, that the two intervals between 1531 and 1607 and between 1607 and 1682 were not quite equal, but he had sagacity enough to see that the differences were no greater than might be accounted for by the attractions of Jupiter and Saturn. Though it was not then possible to compute just what the effect of these attractions would be upon the return of the

comet, he saw that Jupiter's action would retard it, and he accordingly fixed upon the early part of 1759 as the time at which the comet might be expected. Before that date, however, mathematics had so advanced that the necessary calculations could be made." [1]

The great mathematician Clairaut, assisted by Lalande and Madame Lepaute, made a most laborious calculation, selecting April 13 as the date of the perihelion passage, though he considered the result might easily be a month in error owing to the uncertainty regarding the masses of the planets. (Uranus and Neptune were then unknown.) During six months they made elaborate calculations, taking into account the disturbing effects of the planets Jupiter and Saturn on the comet. For this it was found necessary to calculate their distance from the comet, separately, for every degree, for 150 years. The amount of work entailed was stupendous, it showed that the comet would be retarded about 100 days by Saturn and about 518 days by Jupiter. Accordingly, Clairaut, who had taken upon himself the task of computing the perturbations which the comet would probably have experienced since its last appearance, owing to the influence of these two planets, announced to the Paris Academy of Science, towards the end of the year 1758, that the comet might be expected

[1] *Astronomy*, pp. 417-418. Russell, Dugan, Stewart.

to pass its perihelion (the point of its orbit nearest the sun) about April 13 of the following year, though there might be an error of a month either way. Incidentally, he made allowances for the fact "that a body which passes into regions so remote, and which is hidden from our view during such long periods, might be exposed to the influence of forces totally unknown, such as the action of other comets, or *even of some planet too far removed from the sun to be ever perceived.*"

All the astronomers were now looking forward with anxious expectation to the reappearance of Halley's comet. It was first observed by a farmer named Palitzsch, living at Problis, near Dresden, who saw it, on Christmas Day 1758, with a telescope of 8 ft. focus. He was an amateur astronomer, possessed of keen sight, and was in the habit of searching the heavens with the naked eye, which seems to have given rise to the statement that he found Halley's comet with the naked eye at a time when the professional astronomers were searching for it in vain with their telescopes.

The comet reached its perihelion on March 13, just one month earlier than the time assigned by Clairaut, but still within the limit fixed by that illustrious geometer. He would have approached still nearer the truth if he had been in possession of more accurate values of the masses of Jupiter and Saturn, and had been

aware of the existence of the planet Uranus (discovered 1781) and Neptune (discovered 1846). The mass of Pluto, the outermost planet of the solar system (discovered 1930), is too small to have produced much effect in delaying the comet.

The triumphant success of the work accomplished made a deep impression on the scientific world, and as Lalande, the great mathematician, observed : " The universe beholds this year the most satisfactory phenomenon ever presented to us by astronomy ; an event which, unique until this day, changes our doubts to certainty and our hypotheses to demonstration. . . . M. Clairaut asked one month's grace for the theory ; the month's grace was just sufficient, and the comet appeared after a period of 586 days longer than the previous time of revolution, and thirty-two days before the time fixed ; but what are thirty-two days in an interval of more than 150 years, during only one two-hundredth part of which observations were made, the comet being out of sight all the rest of the time ! What are thirty-two days for all the other attractions of the solar system which have not been included ; for all the comets, the situations and masses of which are unknown to us ; for the resistance of the ethereal medium which we are unable even to estimate, and for all those quantities which, of necessity, have been neglected in the approximation of the calculation ? "

In predicting the return of the comet, Halley took into account the newly discovered law of gravitation which had been advanced by Newton. Halley had visited Cambridge in August 1684, with the express purpose of finding out how far Newton had gone in applying the idea of gravity to the attraction prevailing between the sun and planets considered as mere particles when separated by planetary distances.

" Halley was overjoyed to find that Newton had already proved the proposition that bodies attracted gravitationally would describe ellipses; he insisted on this 'and much more' being published, and paid for the publication himself, and his generous insistence was the means of discovering the wonderful proposition that spheres attract as particles at all (external) distances however small—the theory of gravity was complete! The *Principia* appeared in 1687." [1]

Halley did not follow up the possibilities of work opened out by the great discovery of the law of gravitation, probably owing to lack of leisure, until after his appointment as Savilian Professor of Geometry at Oxford in 1704, when he applied the law to the calculation of the orbits of as many comets as he could find records of, according to the principles and methods furnished by Newton, and after " incredible labour "

[1] " Halley's Comet." Address given by Professor H. H. Turner at the Royal Institution of Great Britain, February 18, 1910.

published the elements of twenty-four comets. His attention was attracted by the fact that in three cases the elements bore a close resemblance to one another, as shown with the comets which appeared A.D. 1531, August 24; A.D. 1607, October 16; and A.D. 1682, September 4. Halley conjectured that it was one and the same comet which had appeared three times, travelling in an elliptic orbit, only it did not keep good time, for the interval between the first two appearances was 76 years 2 months; between the second and third, 74 years 11 months. But Halley was ready with an explanation, which we now know to be correct. He laid the blame on the disturbing effects of Jupiter and Saturn. He had observed that they disturbed each other, as should be the case according to the law of gravitation; then would they not also disturb such a flimsy object as a passing comet. A very great disturbance might be capable of sending a comet away for ever beyond the sun's sphere of influence; or a lesser disturbance might lengthen its period appreciably. In fact, he saw no difficulty which could not be explained away in concluding that the interval, inclination, distance, and longitudes of node and perihelion of the three comets were the same. He predicted, therefore, that the comet would return in 1758, giving an illustration of the consequences following from the newly discovered law of gravitation advanced

by Newton. This return he could not hope to witness himself (he died in 1742 at the age of eighty-five), but he trusted posterity, when the comet did reappear, to credit an Englishman with the prediction. The calculations regarding the effects produced by Jupiter and Saturn foreshadowed a greater delay than had been anticipated, and as we have already seen, the comet did not return to perihelion until 1759. But the delay, the causes of which had been foreseen by Halley, added fresh laurels to his success in prediction, and justified his claim to the association of his name with that of the comet for all time.

Halley's brilliant conjecture was justified, a new member was added to the solar system and hopes were aroused as to the possibility of computing the path of his comet, as it may well be termed, at its next return, which occurred in 1835. It furnished an opportunity of testing the progress made by theoretical astronomy during the period of seventy-six years occupied by the comet in making another excursion outward in space, and returning once more to greet us in the neighbourhood of the sun. Taking the perihelion passage of 1759, and following in the steps of Clairaut, Rosenberger of Halle made elaborate calculations relating to the return of Halley's comet in 1835, for which he was awarded the R.A.S. Gold Medal in 1837. He predicted the date November 11, while Lehmann gave that

of November 26. Two French astronomers, Damoiseau and Pontécoulant, independently undertook the task of determining the epoch of the perihelion passage of the comet, making allowances for the disturbing action of the planets, including the planet Uranus, discovered by Sir William Herschel in 1781. It was one of the unknown causes which Clairaut had been unable to take into account, as it was as yet unknown when he made his calculations. According to Damoiseau, the comet should have passed its perihelion on November 4, but according to Pontécoulant this would not occur till November 13, 1835. In 1820, Damoiseau gained the prize offered by the Academy of Sciences of Turin for the best paper on the perturbations of the comet of 1759. On August 5 the comet was seen at Rome. Observations gave November 16 for the exact date of the perihelion, at half-past three in the morning, the difference between the observed date and the mean of the calculated dates being less than three days.

As early as December 1834 astronomers began searching with their telescopes the quarter of the heavens where the wanderer might be expected to reappear. According to a paper published by Dr Olbers in the latter part of that year, the comet might be discovered earlier than was anticipated, at the same time indicating the path it should pursue in the heavens between the December and April to November 1 and 11, 1835.

"He supported this opinion by an examination into the circumstances of its previous apparitions, and by adducing additional evidence founded on the brightness of other comets, particularly of one which appeared in 1811. A call to arms from this celebrated astronomer was not likely to meet with inattention. Many European astronomers sought diligently for the comet about the expected path in December and January, when the part of the heavens between Auriga and Taurus, where it should have been seen, was most favourably placed for examination in a dark sky: all their efforts were in vain."[1]

The first view of the comet was obtained on the morning of August 6, by Father Dumouchel and the astronomers of the Collegio Romano, at Rome, aided by the powerful telescope at the Observatory and the clear, unclouded skies of Italy. The comet was found close to the computed place which at this time was in the neighbourhood of the star ζ Tauri. It was a faint, misty object, scarcely discernible with considerable optical power even under an Italian sky. The presence of moonlight and unfavourable weather during the next fortnight delayed the discovery of the comet elsewhere, but on August 21 it was observed by Professor Struve by means of the fine telescope at Dorpat. Within the following week it was detected by the astronomers of Vienna, Berlin, Kremsmünster, Altona, Breslau,

[1] "The Comets," p. 45, by J. Russell Hind.

and Leyden, as well as by Sir James South, Captain Smyth, and Dr Hussey, in England. Observations made by Professor Rosenberger at Dorpat Observatory on August 20 showed that the perihelion passage would be delayed till November 16, or five days later than he had predicted. During the first three weeks in September the comet gradually increased in brightness but showed no sign of a tail. On the 23rd, Professor Struve saw the comet with the unaided eye, and the following night it was seen by Kaiser at Leyden, though it was not bright enough to attract general attention until the end of the month. It was not until September 24 that it showed any sign of a tail, but it gradually increased in brightness early in October, and could be seen for the five weeks following, in its course through Ursa Major, Hercules, and Ophiuchus. The tail attained its maximum length about the middle of October, but with regard to its actual extent, observers at stations widely distant varied considerably in their estimation.

On October 14 Struve said it was brilliant, and more than 20° long. Next morning it was 24° long as observed at Breslau, and about 20° according to M. Schwabe at Dessau. It was traced fully 30° from the nucleus on October 19 by observers at Madras, and only 15° on the 22nd. From that date it gradually decreased in length and, according to most accounts, it had vanished entirely before the comet sank below the south-

western horizon, about the time of its perhelion passage. Observations of the comet were continued at Kremsmünster by Köller till November 22, and from that date until December 30 the comet was hidden in the glare of sunlight. It was again detected on that date by Kreil at Milan, and observed at some of the more southerly observatories of Europe, as well as at the Cape of Good Hope, where it was observed by Sir John Herschel, who had employed his great reflector in searching for the comet during the winter months of the southern hemisphere, but without avail.

He caught sight of Halley's comet on October 28, 1835, but for the stellar aspect of this body his observations of it would have begun much earlier, for, in the absence of an exact ephemeris, it was impossible to pick it out from among the stars which it so closely resembled. " I am sure," he said, " that I must often have swept with a night-glass over the very spot where it stood in the mornings before sunrise ; and never was surprise greater than mine at seeing it riding high in the sky, broadly visible to the naked eye, when pointed out to me by a note from Mr Maclear " (then Director of the Observatory), " who saw it with no less amazement on the 24th."

In his "Cape Observations" Herschel remarked, after watching with astonishment the changes the comet underwent: "Within the well-defined head, and somewhat eccentrically placed, was seen a

vividly luminous nucleus, or rather an object which I know no better way to describe than by calling it a miniature comet, having a nucleus head and a tail of its own perfectly distinct, and considerably exceeding in intensity of light the nebulous disc or envelope."

The comet alternately lost and regained its tail ; it contracted until it resembled a star, then swelled out into a nebulous globe which gradually vanished as it dissolved into finest air. During the week at the end of January (it had passed perihelion on November 16) Sir John Herschel estimated that the comet had increased its bulk no less than forty times. He suggested that high electrical excitement due to vaporisation, if of the same sign as that of a permanent charge on the sun, would plausibly account for the puzzling appearances he had seen. Bessel, from their close study at the Observatory at Königsberg, had already concluded " the emission of the tail to be a purely electrical phenomenon." He was anticipating the theory now generally accepted that, " as the activity increases, the finer particles, repelled by the sun's light pressure, stream away visibly to form the tail, which grows longer and brighter as the comet approaches perihelion. The emissions from the nucleus sometimes take the form of jets or streams and sometimes the outflow is more regular, resulting in the formation of envelopes." [1]

[1] "Astronomy," pp. 442-443. Russell, Dugan, Stewart.

In Grant's "History of Physical Astronomy" (p. 299), reference is made to the phenomena witnessed on the occasion of the apparition of Halley's comet, both before and after the passage of the perihelion, as highly interesting and suggestive: "Previous to October 2, 1835, the comet presented merely a round nebulous disc, with a faint nucleus in the centre. When observed by Bessel on the evening of that day, the nucleus was found to have suddenly acquired a high degree of brilliancy, and from it there appeared to issue, on the side towards the sun, a cone of light which, after extending to a short distance from the head, was observed to curl backwards as if impelled by a force of great intensity directed from the sun. This outstreaming cone continued to be visible in the form of a luminous sector of a circle until October 22. When observed from night to night it was found to vary constantly in magnitude and brightness. The direction of the axis of the cone was also variable. Bessel discovered by a strict analytical investigation, founded on its observed positions, that it oscillated to and fro on each side of the line joining the comet and the sun. These oscillations were generally very rapid, the lapse of a few hours in some instances sufficing to render them sensible. It is a remarkable fact that the night on which these interesting phenomena first manifested themselves was also signalized by the commencement of the tail of the comet. It is impossible to

doubt that the appendage derived its origin from the nebulous matter which had been in the first instance raised from the head by a force directed to the sun, and was subsequently impelled by a powerful force in the opposite direction."[1]

Professor Struve compared the appearance of the nucleus of Halley's comet about the end of the first week in October to a fan-shaped flame, emanating from a bright point, and subsequently to a red-hot coal of oblong form. On the 12th, according to the same authority, its aspect was astonishing. It seemed like a stream of fire issuing from the cannon's mouth after discharge, when the sparks are driven backward as by a violent wind. At moments the flame was thought to be in motion, scintillating with an undulating motion similar to the flickering of the Aurora Borealis. A second small flame, forming a great angle with the principal one, was also observed. On November 5 the nebulosity without the flames (two being visible) was shaped like a "powder-horn" arched in a most remarkable way. Phenomena of the same kind, described as luminous rays, sectors, etc., were observed by M. Arago at Paris.

[1] Grant's "History of Physical Astronomy," p. 299. In a footnote to this page the author remarks: "A similar appearance was remarked in the great comet of 1618."

CHAPTER V

RETURN OF HALLEY'S COMET IN 1910

NEARLY a century after Halley's death a tabular review of the most probable epochs of perihelion passage of the comet was made by Mr J. R. Hind after he had examined old records, and especially the Chinese annals. These were notified by him in a paper which was read before the R.A.S. in January 1850, entitled "Tabular Review of the Probable Epochs of Perihelion Passage." However, this list of the old returns of Halley's comet given in Mr Hind's book, entitled "The Comets," published as far back as 1852, has since been replaced by the list deduced by Messrs Cowell and Crommelin as given in "Splendour of the Heavens," vol. i, p. 421. The earlier dates are uncertain by many days; the latter ones are known to a small fraction of a day.

In 467 B.C. a bright comet was seen both in Greece and in China, but there is no note of the time of year or of the track through the sky. Nevertheless, Halley's comet was due about that year, and the conjecture of its identity is strengthened by the fact that Aristotle records

that a great meteorite fell at Ægospotami while the comet was visible. Halley's comet is one of those whose orbits approach near enough to that of the earth to provide meteor-showers, and it has been identified with the Aquarids I have seen in early May. This is a well-known shower called the May Aquarids.

From 240 B.C. onwards the dates of return can be given with confidence, but for some of the early ones the date given may be a few weeks wrong owing to the vagueness of the records. (Note: the apparition of 163 B.C. rested till recently on computation only, but a record has now been found in China that a comet was seen in the evening in the first month of 163 B.C.) The records for the apparition of the comet in 12 B.C., October 8, from China and Europe, are unusually full and give complete confidence in the identity.

" The return of the comet, 12 B.C., is of interest from its occurrence within four or five years of the birth of Our Lord. Some people have tried to identify it with the Star of the Magi, but it appears impossible to put the date of the Nativity so far back. The appearance was followed in China in very minute detail; the course was through the Twins, Lion, Herdsman, Serpent, Scorpion, its motion at first being rapid owing to its proximity to the earth. Dr Hind concluded that its orbit must then have been much closer to the ecliptic than it now is.

He gave the inclination as 10°; it is now 18°."[1]

The return of A.D. 66 is probably the sword of fire mentioned by Josephus shortly before its siege, a picture of which, taken from *L'Astronomie*, is given in "Splendour of the Heavens," p. 388. The following is the list of the returns of Halley's comet as amended from Hind's list by means of the calculations of Drs Cowell and Crommelin :—

" B.C. 240, May 15.
B.C. 163, May 20.
B.C. 87, August 15.
B.C. 12, October 8.
A.D. 66, January 26.
A.D. 141, March 25.
A.D. 218, April 6.
A.D. 295, April 7.
A.D. 374, February 13.
A.D. 451, July 3.
A.D. 530, November 15.
A.D. 607, March 26.
A.D. 684, November 26.
A.D. 760, June 10.
A.D. 837, February 25.
A.D. 912, July 19.
A.D. 989, September 2.
A.D. 1066, March 25.
A.D. 1145, April 19.
A.D. 1222, September 10.
A.D. 1301, October 23.
A.D. 1378, November 8.
A.D. 1456, June 2.
A.D. 1531, August 25.
A.D. 1607, October 26.
A.D. 1682, September 14.
A.D. 1759, March 12.
A.D. 1835, November 15.
A.D. 1910, April 19.
A.D. 1986, about February (exact calculations not yet made).

"The round between 1835 and 1910 was the shortest on record, 74½ years; the longest, between 451 and 530, was nearly five years longer, showing the great effect of the planets. It will be seen that Hind's list was seriously wrong in 608, 912, and 1223 (nearly a year too late). Still, great praise was due to him for the

[1] "Splendour of the Heavens," p. 421, chapter on Comets by Dr A. C. D. Crommelin.

list, which was of great help in carrying the perturbations back so as to get the dates with greater certainty."—A. C. D. CROMMELIN.

An accurate knowledge of the dates and circumstances of the returns of 1759 and 1835 was necessary in order that it might be possible to predict accurately its return in 1910. A prize of 1000 marks was offered by the Astronomische Gesellschaft for the most successful prediction, and it was won by Messrs Cowell and Crommelin of the Royal Observatory, Greenwich, who out-distanced all competitors. They computed the return of Halley's comet in 1910 by starting with its known position in 1835, working forward to 1910, then backward to 1759, to connect with the older observations of that year. They also determined the time of every possible passage of the comet back to 240 B.C. Their prediction eventually proved to be correct within three days; that is, within 6′ of arc in R.A. and 4′ in declination, at the date of discovery in 1909.

The following is a description of Cowell's method in connection with determining the time of the return of Halley's comet. The planetary tables enable one to find the position of any planet for many years or even centuries in advance, without going through its course in intervening years; this is because the disturbances that the planets produce on each other are small, and can be expressed in mathematical formulæ.

Owing to the great eccentricity of the comets' orbits, a similar procedure is impossible with them. Cowell's method may be compared to " Dead Reckoning at Sea." One starts by assuming a position and a rate of motion at some selected date. One computes the disturbing action of all the planets during some selected time-interval (one or two days when near the sun, but going up to 256 days when in the Neptunian region.) It is then easy to compute the position and motion at the end of the interval, and thus one goes on *step by step* till the comet has been brought back to the neighbourhood of perihelion. When proper precautions are taken and the time-interval made sufficiently short, the method can be made rigorous. The only drawback is the great labour it involves, but in any case there must be an immense amount of work in finding cometary perturbations.

In the course of its journey outward since 1835 the comet had approached the orbit of Neptune, passing beyond it in 1855 until it reached its greatest distance in 1873, then it began the return journey, crossing the orbit of Neptune again about 1890. It reached the orbit of Uranus in 1903 and crossed that of Saturn in 1908. Meanwhile, it was rapidly increasing its speed, so that it arrived at the orbit of Jupiter the following year, thus bringing it within range of the giant telescopes turned in its direction. There is something eerie in the thought that though the

comet had not been seen for seventy-four years, during which it had travelled millions of miles outward in space, yet, obedient to the attractive power of its ruler the sun, it had been forced to retrace its path, coming once more " within our ken " promptly in 1909, when, according to the law of gravity, the mathematicians predicted it was due.

" Let us suppose," as Professor H. H. Turner suggested during the course of an address on Halley's comet, given before the Royal Institution of Great Britain on the evening of February 18, 1910, " that there were rails laid on the track round the sun on which the comet must travel like a train, without deviating so much as a hair's breadth. There would still remain one element of uncertainty, viz., *the time at which it would arrive.* The disturbance of the planets would now be limited to delays and accelerations such as attend the passage of a train through wayside stations. We must add together all the delays and subtract any time saved. What accuracy may we expect in the final result ? Remember that the whole journey takes seventy-five years, and that there may be unknown disturbing causes." [1]

When the time for the return of Halley's comet, in 1910, drew near, great interest was aroused in the astronomical world. New allies,

[1] It was a near approach to Jupiter in 1835 that hastened the return of Halley's comet in 1910 by over a year.

such as the great 36-in. refractor at the Lick Observatory, which had been erected in 1888 on the summit of Mount Hamilton, California, and the 40-in. refractor, installed a few years later at the Yerkes Observatory at Williams Bay, Wisconsin, as well as other powerful telescopes ; all of which were combined with the camera and pressed into service with the hope of being the first to welcome the wanderer on its return. (Dr Lewis Swift, an American astronomer who specialised in comets, having the discovery of many to his credit, had seen Halley's comet at its apparition in 1835, and was able to welcome it on its return in 1910, but owing to failing eyesight was unable to see it, much to his distress.)

The first to detect the wanderer was Dr Max Wolf, at the Königstuhl Observatory at Heidelberg. He was determined to take no risk of missing the first appearance of the comet, and had placed, as it were, a sentry (in the form of a camera) on guard some time before the comet was due. He was rewarded for the care he had taken, as the impress of the image of the comet was entrapped on the photographic plate at 2 A.M. on the morning of September 11, 1909, while still at a distance of 310,000,000 miles from the sun, and a little farther from the earth. Actually, the first engraving of the image of Halley's comet on a photographic plate was obtained at the Helwan Observatory, Egypt, on August 24, but unfortunately failed to attract attention

until the news of the discovery was cabled by Dr Max Wolf, on September 12, to all the leading observatories. This message was followed by one from the Lick Observatory on September 15, to the effect that a photograph of the comet had been obtained by Dr Heber D. Curtis with the aid of the Crossley reflector. On Wednesday morning, September 15, the comet was sighted with the great 40-in. lens at the Yerkes Observatory by Professor S. W. Burnham, the famous double-star observer. His keen eyes instantly detected the faint misty-looking object, which was photographed on the same date by Dr Oliver J. Lee, who was at work with the 12-in. reflector in an adjacent dome. The comet was again seen by Professor Burnham the following morning about 2 A.M., September 16, and once more it was registered on the photographic plate by Dr Lee. On September 17 the great refractor was in charge of Professor E. E. Barnard, who kindly gave the writer an opportunity to see the faint, misty outline representing the comet, an experience never to be forgotten.

During the month of October the comet began to brighten up; the nucleus increased in size, but by the beginning of November it was still so faint as to be visible only by means of the larger telescopes. The increase in brightness was not very rapid, and as late as the final observations made by Professor Barnard in February the comet gave very little promise of the fine display it

was destined to make later on. Meanwhile, it slowly increased in size, and by March 4, 1910, it presented the appearance of a glowing nebulous object as shown in a remarkable photograph obtained at the Helwan Observatory. Up on the heights, at the Government Observatory at Kodaikanal in southern India, the progress of the comet was recorded by telescope and camera, so that much interesting data accumulated, too numerous to discuss in detail here. In Australia and New Zealand the display was marvellous, as the comet gradually brightened, and a train formed which later on in May was described as reaching from zenith to horizon.

Professor C. P. Olivier, in his book "Comets," gives an interesting account of his personal impressions while observing the comet, due to the wonderful climate at Mount Hamilton, California, the site of the Lick Observatory. "It is doubtful," he remarks, "if anyone besides Dr Curtis actually saw Halley's comet oftener than himself up to the time it ceased to be a naked-eye object in the summer of 1910."

During the latter part of March and early in April it was behind the sun, but later on, as it came into view again, it was photographed at all the leading observatories. A photograph taken at the Lowell Observatory, Arizona, showed that the comet had acquired a tail 9° long, and noticeably bent about 4° from the head. During the

latter part of April the appearance of the tail varied from day to day, dividing into three narrow streamers with a central branch and two symmetrical side branches on the 25th, narrow and straight on the 26th, but branched out again on the 27th. The northern edge was nebulous and not well defined on the 30th, while it appeared bright and well defined on the southern edge. Moreover, the tail near the head was composed of numerous streamers more or less clearly defined in the numerous photographs obtained at various observatories.

So far, the comet had been within reach only by means of telescopic aid, but when the announcement went forth that the comet would be visible to the naked eye the first week in May, enthusiasm was keen among amateur astronomers. On our side of the Atlantic, Halley's comet proved disappointing as far as actually seeing it was concerned, but those who were in the United States had a fine view of the comet on the morning of May 4. A photograph obtained by Professor Barnard at the Yerkes Observatory of that date gave an idea of the imposing splendour of the comet as well as photographs obtained at the Lick Observatory.

On May 6 the head of the comet was of the second magnitude, and the tail was long and divided in two. It was not until the second week in May that the comet began to fulfil in size and brilliancy all that the astronomers had expected.

On May 12 the comet was a wonderful sight, even for the amateur who gazed upon it with the unaided eye. On May 15 Professor Barnard traced the tail of the comet beyond the star θ Pegasi, which would correspond to a length of about 50°. At about three-fourths of its length from the head it was between 3° and 4° broad, and seemed to be straight. The tail had a length of about 70° and a breadth at the end of 8° or 9°, so that it presented the appearance of a closed fan by May 17. On the morning of May 18, the eventful day on which it was expected that the comet would pass between the earth and the sun, the tail made a magnificent display according to accounts given by observers in the Middle West of U.S.A. About 75° of the tail was visible above the horizon, and at least 30° was below it, so that the tail must have been about 105° long.[1]

On the evening of May 18 the head of the comet passed between the earth and the sun, but the supposition that the earth had passed through the tail was denied the next day when reports were received from the Lick and Yerkes Observatories to the effect that the tail of the comet was still visible in the east on the morning of the 19th when it should have been visible in the west. At 2.30 A.M. a soft glow could be seen spreading from below Pegasus and upward as

[1] *Popular Astronomy*, vol. xviii., p. 364, "The Story of Halley and his Comet," by R. E. Wilson.

far as the stars of Cassiopeia. At 2.45 streamers, which later proved to be the comet, were observed reaching from the eastern horizon below Gamma Pegasi and curving upward through Aquarius as far as Altair, and brighter in appearance than the Milky Way. The path of this band of light was very nearly that along which the comet was last seen. Beneath this streamer, and apparently resting along the south-eastern horizon, was a secondary band, not as clearly defined as the upper band, at first mistaken as part of the comet.

"The train of the comet reached the prodigious length of 140° owing to its being so near the earth, and its great curvature was shown by its continuing to be visible in the morning sky for two days after its head had become an evening star.[1] The tail had a much greater curvature than astronomers had inferred from earlier views of the comet. In this case the earth passed through the plane of the comet's orbit before the tail reached us, and thus the encounter was avoided.

A careful look-out was kept for any possible meteorological effects which could have been caused by the earth passing through the comet's tail, but W. J. Humphreys, of the United States Weather Bureau, sums up his investigations based on reports from the whole world as follows: "The halos, coronas, and other phenomena were both

[1] "Splendour of the Heavens," p. 423, chapter on Comets, by Dr A. C. D. Crommelin.

widely scattered and, in some respects, distinctly unusual, and their occurrence coincident, as near as can be determined, with the passage of the earth through the tail of the comet suggests for them a cosmical origin. Still, they were far from universal, and besides, they have all been seen before when there was no comet to which they could be attributed ; and therefore, while admitting the possibility in this case of a cometary influence, it would seem rash, without additional evidence, to conclude that the comet was the principal or even partial cause of the appearances mentioned." [1]

" It may be added," remarks C. P. Olivier, in commenting on the above, " that while no trace of the effects of entering the tail could be detected on any of the critical nights, still, from its relative position on former and later dates, it was concluded that the earth did not pass centrally through the tail but only through its outer edges. Brilliant moonlight, however, was enough to mask entirely any faint glows or other similar appearances in the night skies at the date." [2]

On the evening of May 20 the head of the comet was visible to the naked eye in the west, and it is probable that the earth grazed the edge of the tail on May 21, 1910. The moonlight hid the tail from view until the 25th and 26th, although the comet in the meantime had receded

[1] *Pub. Amer. Astron. Soc.*, ii., 17, 1915.
[2] " Comets," p. 118, by C. P. Olivier.

so rapidly from the earth on its return journey outward that it was no longer conspicuous. Its appearance in the evening sky was not nearly as fine as it had been when seen before dawn in the morning sky. The comet was followed photographically till June 1911, by which time it was 520,000,000 miles from the sun. Then it rapidly grew smaller and fainter as it receded outwards in space, not to be seen again until 1985.

However, we have not lost contact entirely with Halley's comet, as there is a most interesting stream of meteors forming part of its retinue. They are known as the Eta Aquarids, since they radiate from the direction of the star Eta in the constellation of Aquarius. They are to be seen during a period of about two weeks, including the last day or two of April and early May. According to C. P. Olivier, " these meteors were seen as early as 1870, and recognised as a real stream, and various guesses and partial proofs were made showing that they were connected with Halley's comet." It was not until 1909 that he made the necessary observations and calculations rendering the proof complete. He was also the first to prove the daily motion of the radiant, or point in the heavens from which the shower of meteors appeared to emanate as they entered the earth's atmosphere.

" Among other interesting facts brought out was that meteors at least 11,000,000 miles out from the comet's orbit were still moving ap-

proximately parallel thereto, and were evidently part of the system. Altogether it furnished another excellent example of the connection between comets and certain meteor-streams. This proof was soon followed by similar work by Hoffmeister." [1]

Reference is also made to the Aquarids by Dr A. C. D. Crommelin in *The Star World*, pp. 153-154, in which he remarks that "the shower is seen in the morning sky in May, and in 1910 a few meteors belonging to it are stated to have fallen to earth"; if this is so, we can actually handle fragments of Halley's comet.

[1] "Comets," p. 126, by C. P. Olivier.

CHAPTER VI

JOHN RUSSELL HIND, IN CONNECTION WITH HIS WORK ON COMETS; AND THE STORY OF ENCKE'S COMET, AND BIELA'S COMET.

JOHN RUSSELL HIND was born at Nottingham on May 12, 1823. From boyhood he was an enthusiastic student of astronomy, contributing a number of astronomical notes to the *Nottingham Journal* when he was only sixteen years old. In 1840 he secured a post at the Royal Observatory, Greenwich, in the Magnetical and Meteorological Department, where he remained until 1844. On leaving Greenwich he was appointed observer at Mr Bishop's private observatory, in Regent's Park, London.

Mr George Bishop was a successful business man, who had always desired to have an observatory of his own, but the opportunity did not occur until he was more than fifty years of age. When the observatory was finally erected he was anxious that it "should do something," but being unable to accomplish the work personally, he secured the services of capable assistants and

set them to observe with that definite object in view. Among those most carefully selected was Mr Hind, whose discoveries of minor planets as the result of painstaking search were at that time attracting attention. So far only four or five of these small bodies circulating round the sun, between the orbits of Mars and Jupiter, had been discovered, and the number was increased by two, named Iris and Flora, discovered by Mr Hind in 1847. These two discoveries were rewarded by the Royal Astronomical Society with the bestowal of a "Testimonial," and it fell to Sir John Herschel to deliver the address concerning the merits of eleven others who received recognition of their services at the same time. With regard to Mr Hind, he remarked :

"No name comes oftener before the astronomical world as an assiduous observer and able computist in the department of astronomy which the nature of the instrumental means committed to his charge gives him an immediate connection with, as a diligent observer of double stars and computer of their orbits, for instance ; or as the first detector of several comets, one of them a very remarkable one, which from the calculations of its orbit he was enabled to follow up to its actual perihelion, and to behold at noonday presenting a clear and well-defined disc within 2° of the sun. This reminds us that even before the discovery of Iris and Flora Mr Hind was

already a discoverer of comets and an astronomer of distinction." [1]

The comet referred to by Sir John Herschel was discovered by Mr Hind on February 6, 1847, in the constellation Cepheus, and was observed before the perihelion passage till March 24, when it was bright enough to be visible in the strong morning twilight. It was on March 30 that Mr Hind observed it at noonday, and after the perihelion passage till April 24, when it was observed at Berlin and Markree. In his book, "The Comets," p. 168, Mr Hind tells us that the elements of this comet "are probably elliptical to a very sensible degree, but as no thorough investigation has yet been undertaken, we cannot give any fair approximation to the period; still it may be safely stated at several centuries."

The great comet of 1843, one of the finest visible during the nineteenth century, the return of Biela's comet in 1846, the return of Encke's comet in 1848, and its reappearance on January 9, 1852, when it was discovered at Mr Bishop's observatory by Mr Hind, all served to stimulate his interest in comets, as evidenced by his book on that subject. Moreover, he was unhampered by the drudgery of routine work, not having to make a struggle for his own pecuniary advancement, so that he was free to devote his energies to the cause of Science for its own sake. We have ample proof of the way

[1] *M.N.R.A.S.*, vol. lvi., February 1896.

he availed himself of the valuable opportunities which presented themselves in connection with research work. This has already been shown with regard to the arduous task he set himself of tracing backward through the centuries the various apparitions of Halley's comet. The results obtained were of immense value in providing astronomers with valuable data.

The discoveries which have rendered the name of Mr Hind famous include ten minor planets and three comets, besides variable stars and nebulæ. In 1851 he was made a Fellow of the Royal Society, and subsequently he was elected into membership of the Royal Society of Edinburgh, the Imperial Academy of Sciences of St. Petersburg, and the Swedish Royal Society (Lund).

He was also the recipient of many medals, the chief of which were the Gold Medal of the Royal Astronomical Society in 1853 and a Gold Medal from the King of Denmark, Frederick VI, which he decreed should be given to discoverers of telescopic comets. Among the recipients the only English name we find is that of John Russell Hind. He received the Lalande Medal six times (with money prizes amounting to over sixty pounds), and a medal from the French Institute, struck to commemorate the discovery of one hundred minor planets in 1869. The obverse of this medal consisted of the profile of the Englishman, the Frenchman, and the German

who had discovered most of these planets—the Englishman represented being Mr Hind.

"In 1853, he was appointed Superintendent of the Nautical Almanac Office, which position he held till his retirement in 1891. He continued to exercise a general superintendence over Mr Bishop's Observatory, the actual observers being, in succession: Mr Norman Pogson, Dr Vogel, Mr Marth, and Mr Talmage. On the death of Mr Bishop in 1861, when his son, George Bishop, removed the instruments to Twickenham, Dr Hind—as he was now known—remained in charge, maintaining a lively interest in his favourite study of astronomy, and remaining a regular subscriber and contributor to scientific journals at home and abroad." [1]

Although Dr Hind's name seems more intimately associated with his discoveries of minor planets, yet his main work was in connection with comets. Nor was it from the standpoint of discovery, but rather in the examination of old records, and retracing by their names the most probable epochs of the perihelion passage of these celestial wanderers in the remote past. Dr Hind seems to have been specially interested in the study of comets which revolve in elliptic paths, and are termed periodic. These comets are mostly telescopic, the most celebrated being Encke's comet, which had a most striking career. The motions of almost all the comets appear to be

[1] *M.N.R.A.S.*, vol. lvi., February 1896.

just what would be expected of masses moving in free space under the influence of the laws of gravitation, but Encke's comet is one remarkable exception. It is a rather faint object, just visible to the naked eye under the most favourable conditions, and noteworthy for its very short period of 3·30 years—the least so far known.

THE STORY OF ENCKE'S COMET

Encke's comet was first seen by Méchain at Paris on January 17, 1786, when he discovered it as a telescopic object near the star β Aquarii. It was fairly large and bright, with a sensible nucleus surrounded by nebulosity but without the faintest indication of a tail. It was easily distinguishable from a nebula by its movement relatively to the stars. Cloudy weather prevented M. Méchain from observing it except on January 17 and 19, so that no orbit could be deduced from observation. When one of these bodies has been discovered, and several observations have been made—not less than three—they are submitted to calculation, and the *elements of the orbit* are found on the supposition that the real path of the comet through space is a parabola. With these elements we can find for any particular time the comet's distance from the earth and its position in the heavens, thus tracing its course. (How a comet's orbit is deduced from

the observations is given at the end of this chapter.)

On November 17, 1795, Miss Caroline Herschel, sister of the celebrated astronomer, Sir William Herschel, detected a comet with a Newtonian telescope of 27-in. focal length, and a power of about 20; the field of view being about 2° 12′. The comet was not far from the star γ in Cygnus. It was just visible to the naked eye; no nucleus was perceptible, but merely a condensation of the nebulous matter near the centre. The comet was observed at Berlin by Professor Bode on November 10—an amateur astronomer named Carl having announced its visibility — and on the 14th M. Bouvard saw it at Paris. The outline of the nebulosity was nearly if not quite circular, and the greatest apparent diameter was described as amounting to about 5′ of space on the day of discovery. The elements were investigated, on the assumption of parabolic motion, by Dr Olbers, M. Bouvard, and Baron von Zach.

On the evening of October 20, 1805, a comet was found almost at the same time by M. Pons at Marseilles, Professor Huth at Frankfort, and M. Bouvard at Paris. It was situated in the constellation of Ursa Major. The perihelion passage occurred about a month after the discovery, and the comet was observed until within a week of this epoch. The parabolic orbit was computed by Bouvard, Legendre, Bessel, and

Gauss. On November 26, 1818, Pons, of whom we have already learned that he was a most industrious observer, at Marseilles detected a telescopic comet which remained visible till January 12 in the following year. It was soon found that no parabolic orbit could be made to represent the observations within their probable limits of error, and it was this circumstance that induced the celebrated mathematician Encke to undertake a rigorous discussion of the observations, when he speedily found that the orbit of the comet differed markedly from a parabola, being an ellipse of quite moderate dimensions. He saw the probability of its identity with the three comets which had appeared in 1786, 1795, and 1805, seen by Méchain, Caroline Herschel, and Thulis respectively, but it had been taken for a different object on each occasion. By a wonderful feat of computing he carried back the planetary perturbations for thirty-two years in the short space of six weeks. This achievement led to the comet being called Encke's, though he was not the discoverer. (See "Notes on the Lives of Comet-hunting Astronomers," end of Chapter VII.)

As Mr H. T. Colebrooke, then President of the R.A.S., remarked in 1824, on presenting the Gold Medal of the R.A.S. to Professor Encke: "The greatest step which has been made in the astronomy of comets since the verification of Halley's comet, which reappeared in 1759, has

been the identity of Encke's comet, at once determined by the evidence of its frequent appearance within short periods, and already confirmed by its discovery in a distant hemisphere."[1] It might be noted that Charles Rumker and J. L. Pons received the Silver Medal of the R.A.S. in 1824, when Encke received the Gold Medal.

Mr Colebrooke here refers to the fact that, owing to the position of the comet in the heavens about the time of its perihelion passage in 1822, it was not seen at all in Europe, but there fortunately existed an observatory in full activity in Paramatta, New South Wales, founded and maintained by the munificence of a private individual, Sir Thomas Brisbane, the Governor of the Colony. Dr Rumker detected the comet at Paramatta on June 2, and followed it to the 23rd of that month. His observations enabled Encke to rectify the elements, and predict the time of its next arrival at perihelion with the greatest accuracy. He found that it should occur on September 16, 1825.

"The first glimpse of the wanderer was obtained on July 26, 1825, in a position differing from the predicted one by less than 3′ of space. The comet was observed at nearly all the astronomical observatories of Europe until about ten days before perihelion, when it was lost in the sun's rays. It appeared round and very

[1] *R.A.S. Memoirs*, pp. 512-513, 1822.

bright towards the centre, and it was remarked by Professor Alexander in the strong twilight as a small planetary disc, with scarcely any signs of the surrounding nebulosity." [1]

At its return in 1828, when it was discovered during the month of October, and its perihelion passage was due on January 9, 1829, it was a faint hazy-looking object about $1\frac{1}{2}^{\circ}$ in diameter, but six weeks later it was easily visible to the naked eye as an object of the fifth magnitude. It was again observed in 1832 and 1835, when it made a near approach to Mercury and was considerably perturbed in consequence. "It is from these perturbations that the most reliable value of the mass of Mercury has been deduced; Backlund found the value one twenty-seventh that of the earth, or three times that of the moon. It is well to note that the result of the perturbations only becomes manifest in the following return—in this case in 1838. They cause a slight alteration in the speed and direction of motion, but it takes time for an appreciable disturbance of the comet's position to develop. Suppose some small mishap to a motor bicycle caused the speed to diminish by one-tenth of a mile per hour, one minute after the accident the bicycle would be only 3 yards behind the undisturbed position; but five hours later it would be half a mile behind, which would be quite appreciable. It was a near approach to Jupiter in 1835

[1] "The Comets," pp. 61-62, by J. R. Hind.

that hastened the return of Halley's comet, in 1910, by over a year." [1]

At the return of the comet in 1838, while it was under observation for sixteen weeks, Encke made known the fact that its period was shortening. The strong attractive pull of the planets was in no way to blame for the steady decrease in the period of the comet, yet each time it returned to perihelion it arrived two and a half hours earlier. Was it gradually quickening its pace, accelerating spirally, so that eventually it would be absorbed by the sun? Such seemed to be the outlook, but according to Dr Crommelin, "So far it has escaped this fate, since there was no trace of acceleration of Encke's comet on its last return." [2]

The only reasonable explanation of the shortening of its period is that the comet does not move freely through interplanetary space, but meets with an obstacle of some kind which retards its motion—some species of medium of very small density. However, Backlund, who has made a very careful study of the comet at all its returns, finds that the resistance of its motion has decreased, apparently almost abruptly, several times, and he has also shown that the retardation does not take place uniformly all round the orbit, but occurs in a relatively narrow region not far from perihelion.

[1] "Splendour of the Heavens," p. 424, chapter on Comets, by Dr A. C. D. Crommelin.

[2] *Observatory*, pp. 51, 137, 1928.

" Backlund noted that all the changes occurred at times of considerable solar activity, though the evidence is too scanty to assert that this is other than a chance coincidence. It would seem that the density of the resisting medium has diminished at the region where the comet crosses it; this might arise from the orbit intersecting that of a meteor swarm whose density or the position of its orbit was slowly changing. Backlund makes a suggestion to explain the sudden diminution in brightness of the comet after perihelion. It is that the comet particles are flat, and kept in a particular plane by electrical forces. When the earth is in their plane the particles are seen edgewise, and reflect very little light." [1]

THE STORY OF BIELA'S COMET

The story of Biela's comet concerns another short-period comet of extraordinary interest, an account of which is given in Hind's book, " The Comets." It has a period of six and three-quarter years, and was discovered on March 8, 1772, by a French astronomer named Montaigne, of Limoges. The comet was a faint one, with a short tail, and could not be seen with the naked eye. By means of his small telescope Montaigne was enabled to mark its place in the sky, but he had no idea that this foggy little speck of light would become in time one

[1] " Splendour of the Heavens," p. 425, chapter on Comets, by Dr A. C. D. Crommelin.

of the most interesting comets in the solar system. He saw the comet in the constellation Eridanus, but for lack of proper instruments his observations were very crude. Montaigne wrote to the observatory at Paris concerning his observations of the comet, which they saw three or four times before it disappeared.

Thirty-three years later Pons saw the comet, on November 10, 1805, and observed it until the 9th of the following month. It passed rapidly from the northern heavens, and in a month disappeared below our horizon. This time it came very close to the earth, and was visible to the naked eye even in strong moonlight. The elements of the comet very much resembled those of the comet of 1732, and the identity was hinted at by several astronomers, including Olbers and Gauss, the latter assigning as the most probable period 1732 days. Nevertheless, no one seems to have ventured upon a prediction regarding the return of the comet, and the interest in its appearance subsided until its rediscovery in 1826, on the evening of February 27, when it once more attracted attention. On this occasion M. Biela, of Josephstadt, in Bohemia, detected a telescopic comet in the constellation Aries. It resembled a small round nebulosity, with a feeble condensation of light towards the centre. The same comet was observed independently by M. Gambart, at Marseilles, on March 9, by which time it had reached a position in Cetus. There was

no tail or nucleus, and the diameter did not exceed $1\frac{1}{2}'$.

Biela's comet, or Gambart's, as it was called by the French astronomers, now attracted special attention, since it was only in 1826 that the true nature of the comet's path had been determined. It was found that it travels in an orbit of moderate dimensions, carrying it when farthest from the sun to a distance somewhat exceeding that of the planet Jupiter. In fact, it was found to belong to a family or group of comets distinguished by the peculiarity that their paths pass very close to that of Jupiter, suggesting that either these comets have all been forced to take up their present paths through the tremendous attractive influence of the giant planet, or else that at some epoch they were expelled from the interior of Jupiter.

It was soon found that the elements bore a striking resemblance to those of the comets of 1772 and 1805, and what was more important, that no parabolic orbit would represent with reasonable accuracy the observed path of the comet. Clausen,[1] Biela, and Gambart determined the elements of its elliptic orbit, the period differing little from 6·7 years. The identity of the comets of 1772, 1805, and 1826 was therefore rendered extremely probable, although there was some uncertainty in connection with the comet of 1772, which was very imperfectly observed, and

[1] See "Notes on the Lives of Comet-hunting Astronomers," end of Chapter VII.

was only followed by M. Montaigne during a brief interval of twelve days.

Santini and Damoiseau assigned November 27, 1832, as the date of this comet's return to its point of nearest approach to the sun. Professor Santini determined the effects of planetary disturbances, and he ascertained that the most probable value of the periodic time in 1826 was 2455·176 days, and that the comet had arrived at its perihelion point on March 18, at 10 P.M., Paris time. Then he calculated the disturbing effects due to the attraction of Jupiter, Saturn, and the earth, shortening the next revolution some 10·023 days by their combined influence, so that the comet should again arrive at perihelion about 2 A.M. on November 27, 1832. Then Baron Damoiseau was led to infer from a similar investigation that the return of the comet would be accelerated by 9·664 days—a result not very widely differing from that of Santini.

Olbers confirmed this result, showing, moreover, that the comet's course would bring it within 20,000 miles of the earth's path, and drawing attention, in a paper written in 1828, to the very close approach of the orbits of the earth and comet at the descending node of the latter. In 1832 he found that the comet would be nearer the sun than the earth, and would therefore pass inside our annual path, or less than five terrestrial semi-diameters.

Remarking on the fact that the comet's course

would bring it within 20,000 miles of the earth's path, Sir John Herschel wrote, in 1866, "The orbit of this comet very nearly intersects that of the earth at the place which the earth occupies on or about November 30. If ever the earth is to be swallowed up by a comet, it will be on that day of the year. In the year 1832 we missed it by a month. The head of the comet enveloped that point of our orbit, but this happened on October 29, so that we escaped that time. Had a meeting taken place, from what we know of comets it is probable that no harm would have happened, and that nobody would have known anything about it."

It is important to notice how closely the calculations of astronomers agreed with the actual facts in connection with the comet's return after its orbit had been calculated. After 1826 the comet was out of sight for nearly six years, during which time it was exposed to more or less disturbing influences, yet the calculations of the astronomers were not far out, since the actual difference between the observed and calculated time was less than twelve hours. To illustrate this by a terrestrial instance, the case is much the same as though an express train from Edinburgh should arrive in London within a second of the appointed time—a degree of accuracy not invariably attained, though the terrestrial engineer has the power, which the comet lacks, of making up for lost time.

The first glimpse of the comet at its reappearance in 1832 was obtained by the observers of the Collegio Romano at Rome, on August 23; a month later it was observed by Sir John Herschel, with his 20-ft. reflector, at Slough, and about the end of the third week in October it became more generally visible. He saw it pass centrally over a group of small stars of the 16th and 17th magnitude. The slightest bit of haze would have blotted out the stars. Through the comet, however, they resembled a nebula, partly resolvable into stars. We do not know how thick the cometic matter was. About the end of the third week in October the comet became more generally visible, and it was last seen at the Cape of Good Hope on January 3, 1833. It was always faint, with but little or no central condensation, and was at no time perceptible without a good telescope. The comet arrived at perihelion only twelve hours before the computed time, which was a much closer fulfilment of prediction than could have been expected.

In 1839 the comet returned, but was not seen owing to the position of the sun at the time when the comet was in our neighbourhood. Throughout its passage near us, in fact, the comet was lost to sight in the splendour of the sun's light. The next return, in 1846, was anticipated with the greatest interest. According to the calculations of Professor Santini—to whom we are indebted for nearly the whole of our knowledge of the move-

ments of the comet since 1826—the influence of Jupiter being very considerable, indicated an acceleration of the ensuing arrival at perihelion by 31·884 days. The perihelion passage was fixed for about 9 P.M. Greenwich time on February 11, 1846, and it was found the comet would remain visible a long time, thus affording an opportunity for correcting the theory of its motion by long-continued observation.

As the time drew near, great enthusiasm prevailed among those in search of the wanderer, and powerful telescopes which were to be found in many of the European observatories were used to good advantage. It was discovered on the same evening, November 28, 1845, by Professor Encke, at Berlin, and Signor Di Vico, at Rome. Professor Challis saw it on December 1, with the great Northumberland Equatorial, at Cambridge, but it was not generally recognised till the third week of December, and was last seen on April 27, 1846, at the observatory at Bonn.

And now one of the most singular events recorded in the history of comets took place. In 1846 "all seemed," says Sir John Herschel, "to be going on quietly and comfortably, when behold! suddenly, on January 13, the comet split into two distinct comets! each with a head and coma and a little nucleus of its own. There is some slight contradiction about the exact date. Lieutenant Maury, of the United States Observatory of Washington, *reported officially on the*

15*th*, *having seen it double on the* 13*th*, but Professor Wichmann, *who saw it double on the* 15*th*, *avers that he had a good view of it on the* 14*th*, and remarked nothing particular in its appearance. Be that as it may, the comet from a single became a double one. What domestic troubles caused the secession it is impossible to conjecture; but the two receded farther and farther from each other up to a certain moderate distance, with some degree of mutual communication, and a very odd interchange of light—one day one head being brighter, and another the other, till they seem to have agreed finally to part company."

The two companion comets had each a tail, as well as a head, coma, and nucleus. Then, as they were passing out of view in 1846, the two comets seemed to approach each other. The greatest distance between them was attained on or about March 3, 1846, and amounted to about 157,000 miles. On the return of the double comet in 1852 the distance had increased to about 1,250,000 miles. In 1858 the comet probably returned; but, as in 1839, the part of the heavens traversed by it was too near the sun's place to permit the comet to be seen. But what happened to the comet during its passage past the sun in 1858 is not known. It should have been seen at the next return, or in 1866, but 1866 came, the path of the comet was assigned, and the astronomers looked forward with interest to its reappearance, eager to see how far the two

comets had separated from each other—*and no comet appeared.*

"Telescopes of great power and exquisite defining qualities swept the whole track on which the comet was to have travelled; nor were the neighbouring regions of the heavens left unexplored; but not a trace of the comet could anywhere be seen. There was not the slightest room for questioning the accuracy of the calculations by which the path had been predicted. Astronomers were certain that, if undestroyed or undissipated, the comet would follow the assigned path—as certain as a station-master would be that a train would enter a station along the line of rails assigned to it, unless some accident or mistake should occur. Now comets do not make mistakes; but, as we now see, they are not free from the risk of accidents. This comet had already met with an accident, being broken by some mischance into two parts under the very eyes of astronomers. Probably in 1859 it met with further misfortunes, visible, mayhap, to astronomers in Venus or Mercury. At any rate, something had happened to the comet since its retreat in 1852." [1]

In February 1866 Sir John Herschel wrote, with regard to the missing comet: "It is now overdue! Its orbit has been recomputed, and an ephemeris calculated. Astronomers have been eagerly looking out for its reappearance for the last two months, when, according to all former

[1] "Our Place Among Infinities," p. 81, by R. A. Proctor.

experience, it ought to have been conspicuously visible—but without success! giving rise to the strangest theories. . . . Can it have come into contact or exceedingly close approach to some asteroid as yet undiscovered; or, peradventure, plunged into, and got bewildered among, the ring of meteorolites, which astronomers more than suspect?"

Apparently the comet had ceased to exist, but its fragments had not been absolutely destroyed, so that in November 1872 astronomers expected to see the débris of Biela's comet. A meteor-shower which occurred on November 27, 1872, justified their expectations, furnishing important evidence of the connection between meteors and comets which had already been shown by the meteors of November 13 to 14 (called the Leonides) which travel in the track of Tempel's comet of 1866; and the August 10 to 11 meteors, or Perseides, which follow in the wake of the bright comet of 1862, known as Tuttle's comet.

The display of meteors associated with Biela's comet, which occurred on November 27, 1872, was remarkable in many ways. The meteors were far more numerous than during the memorable shower of the night between November 13 to 14, 1866, when, it is said, the meteors fell "as thickly as snowflakes."

H. A. Newton, in a lecture given on March 9, 1874, at the Sheffield Scientific School of Yale

College, U.S.A., described the appearance of the shower of meteors as seen in the early part of the evening of November 27: "They came upon us in crowds. Over 1,000 were counted in an hour. By nine o'clock the display was over. But we saw only the last few drops of a heavy shower. Before the sun had set with us the shooting stars were seen throughout all Europe, coming too fast to be counted. At least 50,000, perhaps 100,000, could have been seen there by a single party of observers."

The following description given by Professor Grant is of special value, because of his skill and practice as an observer: "In their general features the meteors did not differ from those of the great display of November 13 to 14, 1866. They were, however, obviously less brilliant. Their normal colour was white, with a pale train tinged now and then with a very faint greenish hue. The head seldom equalled in brightness a star of the first magnitude. From time to time, however, a meteor of unusual splendour would appear, nearly rivalling Jupiter in brightness. In such cases the train, especially when breaking up, exhibited a reddish tinge. In two instances of large meteors (those of 8 hours 13 mins. and 9 hours 33 mins.), the colour of the train was conspicuously green. In general, however, there was an absence of the brilliant emerald hue which formed so conspicuous a feature of many of the large meteors of November 1866. The

time of visibility of a meteor did not exceed 2 or 3 secs. In two or three instances of bright meteors, however, the débris of the train remained visible for about 30 secs. The arc described varied as usual from zero to 40° or 50°.

"The radiant point of the meteors occupied a position midway between γ Andromedæ and 51 Andromedæ, perhaps a little nearer to the former star than to the latter. Assuming the position of the radiant point to be midway between the two stars just mentioned, it would thus be situated in R.A. 26°, Dec. N. 44°. This conclusion was supported by the observations of nearly stationary meteors in the vicinity of the radiant point. On the other hand, the courses of the more distant meteors, when traced back, although in general assigning the same position to the radiant, appeared in many instances to come from a higher region, situated in Cassiopeia."

The maximum of the shower occurred about 8 hours 10 mins. The aggregate number of meteors counted from 5 hours 30 mins. to 11 hours 50 mins. (by one observer) amounted to 10,579. To this it may be added that in Italy the shower was even richer, for Signor Denza states that in 6½ hours no less than 33,400 meteors were counted by four observers. "The meteors were very brilliant," he adds, "and were noticed in every part of the sky. The number recorded above is far less than the

truth, for we found it frequently impossible to count them. The maximum display took place between 7 hours and 9 hours, and for 21 mins., between 6 hours 35 mins. and 6 hours 56 mins. *the appearance of the sky was that of a meteoric cloud.* The radiant point was very clearly indicated near γ Andromedæ."

It occurred to the German astronomer Klinkerfues that if search could be made in the part of the heavens directly opposite to that whence the meteor-shower had appeared to radiate, the cluster of meteoric bodies which had produced the display might be detected. He telegraphed to Mr Pogson (the Government Astronomer) at Madras, "Biela touched earth November 27. Search near Theta Centauri." And Pogson understood that it was the comet itself that he was searching for, since he wrote as follows, in describing the results of his search: "I was on the look-out from comet-rise (16 hours) to sunrise the next two mornings, but clouds and rain disappointed me. In the third attempt, however, I had better luck. Just about 17¼ hours mean time a brief blue space enabled me to find Biela, and though I could only get four comparisons with an anonymous star, it had moved forward 2·50 in 4 mins., and that *settled* its being the right object. I recorded it as 'Circular, bright, with a decided nucleus, but no tail, and about 45″ in diameter.' This was in strong twilight. Next morning, December 3, I got a much better

observation of it ; seven comparisons with another anonymous star ; two with one of our current Madras Catalogue Stars, and two with 7734 Taylor. This time my notes were : 'Circular, diameter 75″, bright nucleus, a faint but distinct tail, 8′ in length and spreading, position angle from nucleus about 280°.' I had no time to spare to look for the other comet, and the next morning the clouds and rain had returned."

"While whatever the object seen by Pogson may have been, it was not Biela's comet ; for the comet was due in that part of its orbit no less than twelve weeks earlier, and any retardation which could have produced so great a delay would have altogether changed the character of the comet's path. Still it might be supposed that certainly what Pogson saw was on the track of Biela's comet, was in fact the cluster of bodies which produced the meteor-shower of November 27. Even this, however, is so far from being demonstrated that skilful mathematicians consider the object seen by Pogson to have had no connection whatever either with Biela itself or its meteoric train. This, at any rate, is certain—a flight of bodies travelling on the track of Biela's comet, and crossing the earth's orbit on November 27, could not possibly have been seen in the positions in which Pogson saw a cometic or cloudlike object. . . . Hence we may be assured that if the object seen by Pogson was connected at all with the meteor-cloud through which the earth passed

on November 27, he saw a much denser part of the meteor-cloud, and there is no reason why this dense portion or nucleus of the meteor-cloud may not have been at a considerable distance from the earth on November 27, 1872. This consideration would serve to remove some of the more perplexing circumstances of the recent observations." [1]

ANOTHER LOST COMET OF SHORT PERIOD

A comet found by Brorsen at Kiel, on February 26, 1846, is the second lost comet of short period which has been observed. Its orbit was proved to be an ellipse with a period of about five and a half years. "It was well placed for observation at alternate returns, being missed in 1851, seen in 1857 (fairly bright and large), missed in 1862, observed in 1868, 1873, and 1879. At the last return it was bright enough for observations to be made of its spectrum, which was of the usual hydrocarbon type. It has never been seen since 1879, though it was carefully sought for in 1890, when its position, as calculated, was quite favourable. There was no very close approach to Jupiter about this time to account for the disappearance. It must have been near Jupiter in 1842, before it was discovered, but another close approach is not due till 1937. Its

[1] "Our Place Among Infinities," pp. 103, 108, by R. A. Proctor.

disappearance illustrates the general fact that we cannot predict that any of the short-period comets will actually be observed in a particular year. In several cases, even when the perturbations have been calculated, and the conditions seem favourable, search has been made in vain." [1]

HOLMES' COMET OF 1892

Here we have an instance of a comet which behaved in a most unusual manner. When found it was very bright and in the same field of view with the Great Andromeda nebula. It must have brightened fairly rapidly, as photographs of the region failed to show it, which had been taken not long before. It then began to expand, growing fainter in the process, with the result that at the end of two months it was practically impossible to observe it further. "Then, to the surprise of astronomers, a new bright region appeared, in the middle of it, which in turn expanded, and grew fainter. We may conjecture that something in the nature of an explosion occurred on each occasion, driving the cometary matter violently outwards. The comet was seen again in 1899 and 1906, but never repeated its brilliant display of 1892. In 1919 it could not be found, though its position was favour-

[1] "Splendour of the Heavens," pp. 427-428, chapter on Comets, by Dr A. C. D. Crommelin.

able, so it probably affords another case of disintegration." [1]

According to Dr Crommelin, "The career of a comet may be said to be over when its meteors have lost all their gas, or when they have been scattered by perturbations over so wide a space that its unity and visibility are lost. These disrupting causes are most effective when a comet is fairly near the sun, therefore the oftener a comet approaches the sun the shorter the period of its existence as a comet. I think, therefore, that we can ascribe the great prevalence of long-period comets to the survival of the fittest." [1]

HOW A COMET'S ORBIT IS DEDUCED FROM THE OBSERVATIONS

In "Splendour of the Heavens," p. 429, Dr A. C. D. Crommelin gives the following explanation of the method by which a comet's orbit is deduced from the observations: "Three observations are required to obtain an orbit; each observation consists of two elements, which are called Right Ascension and Declination, corresponding exactly with longitude and latitude on a terrestrial map. We thus have six observed quantities which, conjoined with the times of observation, enable us to deduce the six elements of the orbit; these are (1) the time of passing

[1] "Splendour of the Heavens," p. 427, chapter on Comets, by Dr A. C. D. Crommelin.

perihelion ; (2) the direction of the perihelion point looking from the sun ; (3) the direction of the ascending node or point where the comet crosses the plane of the earth's orbit from south to north ; (4) the inclination or slope of the orbit to that of the earth ; (5) the distance from the sun at perihelion ; (6) the period of revolution, or the eccentricity. We can deduce one from the other when we know (5), viz., the distance from the sun at perihelion.

"In the case of an elliptical orbit we need all the six observed quantities, which in some cases yield one solution and in others two solutions ; but if we commence by assuming the orbit parabolic (which is generally done in the case of new comets), we treat (6) as known, the eccentricity being unity and the period infinite ; we need then only five observed quantities, and the accuracy with which the sixth quantity fits in with the deduced orbit is a test as to whether the orbit is really parabolic ; but it is not safe to assume an elliptical orbit from a short observed arc, as the discordance may simply arise from want of precision in the observations. A comet is frequently ill-defined and difficult to observe accurately. Without entering into mathematical details we may note that the distance of the comet from the sun is deduced from the curvature of the observed arc, that is, the amount by which the three observed positions, when plotted on a diagram, deviate from a straight line. Part of the

curvature is due to the fact that the earth, from which our observations are made, is itself following a curved path round the sun. A trial-and-error method is generally necessary to separate the curvature due to this source from that due to the comet itself.

" Lambert deduced an elegant theorem: if the observed arc is concave towards the sun, then the comet is nearer the sun than the earth is; if the arc is straight, the distances of comet and earth from the sun are equal; if it is convex towards the sun, the comet is the more distant. This test fails if all three positions lie on (or very close to) the ecliptic, in which case the plane of the orbit agrees with that of the earth's orbit and the arc appears straight at all distances. We then need a fourth observation to find the orbit elements, which are deduced from the change of rate of motion of the comet instead of the curvature, which is now zero."

SEARCH FOR NEW COMETS BY AMATEURS

" There are now very few astronomers engaged in the search for new comets, and this may be recommended as a hopeful field of work for the amateur who possesses a small telescope. He should use his lowest power, and sweep by preference over the low western sky just after dark, or the low eastern sky just before the dawn. A

comet may, however, be found in any region of the heavens. In cases where a tail is present, the cometary nature of the body may be at once manifest; but in most cases a new comet appears as an ill-defined misty patch, and there is danger of confusion with nebulæ. In these cases no definite announcement should be made until the object has been seen to move among the neighbouring stars. A careful diagram of the field should be made, and repeated an hour later. The observer must not be deceived by the apparent rotation of the field produced by the diurnal motion. A star that is high left of another east of the meridian will appear high right after passing the meridian. This change corresponds to a page of a book being slowly turned round, whereas the change required to prove the cometary character of the body corresponds to one letter on the page slipping out of its place in a word. If the discovery is confirmed by observed motion, prompt and full information should be sent to official astronomers; the discoverer, if first in the field, will have the satisfaction of having his name permanently attached to the body. There are now no exceptions to this rule, though in the past there are some cases where the names of men who have made extended researches on a comet are substituted for the actual discoverers. Halley's and Encke's comets are examples." [1]

[1] "Splendour of the Heavens," pp. 429-431, chapter on Comets, by Dr A. C. D. Crommelin.

CHAPTER VII

PIONEER COMET HUNTERS

Tebbutt in New South Wales: Denning in England: Reid and Forbes at the Cape: E. E. Barnard in U.S.A.

MR JOHN TEBBUTT made a name for himself in connection with his cometary observational work in Australia. His family emigrated from England in 1801; John was born at Windsor, N.S.W., in 1834. At the age of eleven he read some popular articles on astronomy by Mr Hind, the well-known London astronomer, and thus began his interest in that subject. His early efforts were hampered for the want of instruments, as he had only an ordinary marine telescope and a celestial atlas.

" My earliest attempt that I can remember," he tells us, " in the way of celestial observation, was in May 1853, when a comet, rather conspicuous to the naked eye, was visible near the foot of the constellation Orion. By means of an ordinary marine telescope and a celestial atlas I fixed the apparent positions of the comet by alignment with the stars in its immediate

neighbourhood. During the first week in May the comet's path lay between the foot of the constellation already named and the bright star Sirius. These observations, with accompanying sketches, form the first entries in a journal which I then commenced in connection with astronomical work." [1]

Later on he purchased a sextant and a copy of Norie's "Epitome of Navigation." He also had the use of an excellent Scotch eight-day clock, of the grandfather type, with a seconds pendulum. In the early days he was accustomed to regulate the clock by sextant observations, and also by transits of the sun and stars over two fixed plumb-lines adjusted at a considerable distance from each other and in the plane of the meridian. He calculated a rough orbit for comet 1853 II., from places charted by him in May of that year. "These were my first attempts," he tells us, "to calculate a cometary orbit, and I well remember the pleasure which the results afforded me."

In the year 1858 Donati's comet made its appearance, and by the middle of August its orbit had been determined by northern astronomers.

"It subsequently came south, and was well seen during the months of October and November. This beautiful object furnished me with another opportunity for employing my imperfect instrumental appliances. I obtained a good series of measurements with my sextant

[1] "Astronomical Memoirs," pp. 10-11, by John Tebbutt.

during the months above named, from which I also calculated the orbit." [1]

In July 1860 another comet, referred to as 1860 III., became an object of popular interest in Australia, and Tebbutt observed this with his sextant, deducing from the resulting observations a satisfactory orbit. Its accuracy was confirmed by comparison with results obtained by the Rev. W. Scott, the first Government Astronomer, from more satisfactory positions obtained with a small equatorial at the Sydney Observatory.

Mr. Tebbutt's discovery of the great comet of 1861, and another in 1881, the orbits of which he computed from his first observations, made his name well known in the astronomical world. He discovered the comet 1861 II. on May 13, a month prior to its perihelion passage on June 11. Soon after its discovery it rapidly increased in brilliancy, and became at length one of the most magnificent objects of its kind in the annals of astronomy. The tail branched in two, and the angle between the two tails increased rapidly towards the end of June as the earth and comet approached each other. This was due to the perspective effect of the mutual approach. It may be interesting to note that at this period there were no means of cabling comet discoveries to Europe, and so the inhabitants of the northern hemisphere were quite unaware that a great comet was approaching the earth, and that the

[1] "Astronomical Memoirs," p. 14, by John Tebbutt.

earth itself would probably be involved in its tail.

Few comets created a greater sensation than the Great Comet of 1861. Passing from the southern hemisphere into the northern, it became visible in England on June 29, though it was not generally seen till the next evening. In a letter published at the time in the London *Times*, Mr Hind stated that he thought it not only possible but even probable that some time on Sunday, June 30, the earth passed through the tail of the comet at a distance of perhaps two-thirds of its length from the nucleus.

"The head of the comet," according to an account given in Chambers' "Descriptive Astronomy," edition 1867, "was in the ecliptic at 6 P.M. on June 28, at a distance from the earth's orbit of 13,600,000 miles on the inside, its longitude, as seen from the sun, being 279° 1′. The earth at that moment was 2° 4′ behind that point, but would arrive there soon after 10 h.p.m. on Sunday, June 30. The tail of a comet is seldom an exact prolongation of the radius vector or line joining the nucleus with the sun: toward the extremity it is almost invariably curved, or in other words, the matter composing it lags behind where it would be if it travelled with the same velocity as the nucleus. Judging from the amount of curvature on the 30th, and the direction of the comet's motion as indicated by the orbit which he had already published, Mr Hind thought that the

earth very probably encountered the tail at the early part of that day, or at any rate, that it was certainly in a region which had been swept over by the cometary matter a short time previously. In connection with this subject, he adds that on Sunday evening, while the comet was so conspicuous in the northern heavens, there was a peculiar phosphorescence or illumination of the sky, which he attributed at the time to an auroral glare ; it was remarked by other observers as something unusual, and, considering how near we must have been on that evening to the tail of the comet, it may be a point worthy of investigation whether such an effect can be attributed to this proximity.

" If a similar illumination of the heavens had been remarked generally on the earth's surface, it would be a significant fact. Mr Lowe of Highfield House confirmed Mr Hind's statement of the peculiar appearance of the sky on June 30. The sky, he says, had a yellow auroral glare-like look, and the sun, though shining, gave but feeble light. The comet was plainly visible at a quarter to 8 o'clock (during sunshine), while on subsequent evenings it was not seen till an hour later. In confirmation of this he adds, that in the parish church the vicar had the pulpit candles lighted at 7 o'clock, which proves that a sensation of darkness was felt even while the sun was shining. Though he was not aware that the comet's tail was surrounding our globe, yet he was so struck

by the singularity of the appearance that he recorded in his daybook the following remark: 'A singular yellow phosphorescent glare, very like diffused aurora borealis, yet, being daylight, such aurora would scarcely be noticeable.' The comet itself, he states, had a much more hazy appearance than at any time after that evening." [1]

In his "Astronomical Memoirs" (p. 23), Mr Tebbutt remarks, in connection with the above statement, that auroral phenomena were generally seen in New South Wales about the time of the comet's nodal passage. It is, moreover, recorded in his journal, that "in the evening of June 30 I observed a peculiar whitish light throughout the sky, but more particularly along the eastern horizon. This could not have proceeded from the moon, but was probably caused by the diffused light of the comet's tail, which we are very near to just now."

The fan-like appearance of the tail was very noticeable not only in Australia but in England, as the comet receded from the earth after its close approach. Professor D. P. Todd, in his "Stars and Telescopes," writing of this comet says:

"This remarkable body, discovered May 13, 1861, by Mr Tebbutt of New South Wales, has a tail which appeared to stretch one-third of the way round the heavens. The earth and moon passed through the tail of this body, June 30,

[1] "Descriptive Astronomy," edition 1867, by G. F. Chambers.

1861, with no apparent effect save a peculiar sky glare. According to Sir John Herschel, this comet far exceeded in brilliancy all other comets that he had ever seen, even those of 1811 and 1858."

"It appears," to quote further from Mr Tebbutt's "Astronomical Memoirs," "then, from what I have gathered from several sources, that my predictions as to the near approach of the comet's tail to the earth were completely verified. I communicated to the *Monthly Notices of the Royal Astronomical Society*, and to the *Astronomische Nachrichten* in 1878, a brief statement of the orbit elements, and my prediction, which was published in those journals. I will now close these remarks on the great comet of 1861 by stating that a complete investigation of the orbit from all published observations was made by Professor Heinrich Kreutz, of Kiel, in 1880, in which he did me full justice as the first discoverer of the comet, and also the first computer of its approximate orbit. In his classical work he gives the period of revolution as 409·4 years, so that we may look out for its next visit about the year 2271. My sole regret in connection with this comet is the circumstance that my instrumental means did not admit of my accurately observing it and thus contributing to the data employed in Dr Kreutz's investigations."

In November 1861 Mr Tebbutt purchased an excellent refracting telescope by Jones of Liverpool, England, of $3\frac{1}{4}$-in. aperture and 48-in.

focal length, which was soon provided with two ring-micrometers by Tornaghi, of Sydney. His equipment now consisted of a sextant, a good common eight-day clock, beating seconds, and the telescope just referred to. With the last-named instrument he had the pleasure, he tells us in his "Memoirs," "of making my first acquaintance with Encke's celebrated periodical comet on the morning of February 16, 1862, but the comet was too faint for good observation. I soon afterwards found an opportunity for turning my modest equipment to account. In the beginning of September a comet discovered by Swift in the United States, on July 15, came south, and was a conspicuous object to the naked eye. My telescope was as yet only mounted on a tripod-stand without divided circles of any kind, its location being under the veranda of my father's residence, and in such a position that the beats of the clock were just audible. The clock itself was regulated from sextant observations. The comet was compared with stars by means of one of the ring-micrometers. The comparison stars were identified by observing their transits across the diaphragm of the telescope in connection with other stars plainly visible to the naked eye, these latter being themselves identified by sextant observations. The difficulties thus surmounted can well be appreciated by practical astronomers. The results of these observations, together with determinations of the orbit (of Tuttle's 1862

III. comet), formed the subject of two papers read by me before the Philosophical Society of New South Wales. They were also forwarded to the Royal Astronomical Society, and the *Astronomische Nachrichten*, and they constituted my first attempt to bring my work before the professional astronomers of the Northern Hemisphere. The comet is an exceedingly interesting one, and is associated with the well-known August meteors." [1]

At the close of 1863 Mr Tebbutt erected a small observatory, wholly the work of his own hands, and in accomplishing it he combined the handicrafts of the carpenter, the bricklayer, and the slater. Towards the close of 1864 it was complete, the instruments with which it was furnished being a 2-in. transit instrument, an eight-day, half-seconds, box-chronometer, and the $3\frac{1}{4}$-in. refracting telescope already referred to. The transit instrument was provided with two sets of mountings, one on one of the meridian piers and the other on the prime vertical pier. In this way the instrument could be employed for observations both in the meridian for time and in the prime vertical for latitude. A small octagonal tower rising from the centre of the observatory and covered by a conical revolving roof accommodated the small telescope.

[1] "Astronomical Memoirs," by John Tebbutt, pp. 25-26, being a popular and complete account of the astronomical work done by him at the peninsula Windsor, New South Wales, from the year 1853 to the close of 1907.

COMETS

The following is a brief account of some of Mr Tebbutt's other cometary observations, showing the way he kept in touch with the discoveries of comets made by astronomers in all parts of the world. For instance, in 1864 he observed Comet II. of that year, which was discovered by Tempel at Marseilles on July 4, and subsequently became visible to the naked eye in New South Wales. As we have already seen, there were no cable messages from Europe in those early days, so that astronomers in Australia did not hear from the Northern Hemisphere for some weeks, but it was then found to have been a conspicuous object in the northern skies. In January 1865 a brilliant comet appeared, which, from its position, could not be seen in the Northern Hemisphere. It was observed at five stations only, namely, Cape of Good Hope, Melbourne, Port de France, Santiago, and Windsor, N.S.W. It was observed at Windsor with the 3¼-in. telescope from January 30 to March 23, and the observations, with the derived orbit elements, were forwarded to Europe. The orbit is sensibly parabolic.

It will be seen from a previous statement that Mr Tebbutt had a view of Encke's famous comet for the first time, at its return to perihelion, in 1862. It was again detected by him on June 24, at its return in 1865. In 1879 Brorsen's periodical comet, which was first discovered by Tempel at Arcetri, Italy, on January 14, was not seen again

till it was found on February 22 by Mr Tebbutt, during the course of his observations at Windsor. In 1880 a great comet made its appearance above the south-west horizon in February, but inasmuch as the head could not be seen, no observation of any value could be obtained at Windsor.

"It arrived at perihelion at thirty-six minutes past eleven o'clock, Sydney mean time, in the forenoon of January 28, at a distance of 621,380 miles from the sun's centre. It must therefore have passed the sun's surface at a distance of only 190,480 miles, so that the heat to which it was subjected must have been beyond human conception. It appears that the comet was only three hours on the north side of the plane of the earth's orbit, and that in this short interval it described an angular path of 180° as seen from the sun. On the evening of January 17, when the Melbourne observers obtained their last position, it had receded to a distance of 75,000,000 miles from the sun, being at the same time 69,500,000 miles from our planet. This comet is exceedingly interesting, inasmuch as it belongs to a family of comets revolving in orbits closely resembling the great comet of 1843." [1]

In 1881 Mr Tebbutt discovered a comet while scanning the western sky with the unaided eye on the evening of May 22. He observed a

[1] "Astronomical Memoirs," p. 47, by John Tebbutt.

hazy-looking object just below the constellation Columba, which from his familiarity with that part of the heavens he regarded as new.

"On examining it with a small marine telescope, I found it consisted of three objects, namely, two stars of the $4\frac{1}{2}$ and $5\frac{1}{2}$ magnitudes, afterwards identified as γ^1 and γ^2 Coeli, and the head of a comet. I could not find any trace of a tail, but on the 25th it exhibited a tail about 2° in length. Immediately on its discovery I obtained, with the $4\frac{1}{2}$-in. equatorial, eight good measures of the nucleus from one of the bright stars just mentioned. On the following day I notified the discovery to the Government Observatories at Sydney and Melbourne. . . . On the evening of the discovery, May 22, the comet was distant 82,000,000 miles from the sun and 71,000,000 from the earth. At my last observation, namely, on the morning of June 12, these distances had diminished to 69,000,000 and 33,000,000 miles respectively. The comet passed its perihelion 68,000,000 miles from the sun at about half-past five o'clock, Sydney mean time, on the morning of June 17, and about half-past ten o'clock on the evening of the 19th, it reached the plane of the earth's orbit at the ascending node. . . . After the comet left our southern skies it became a fine object to northern observers. In the opinion of some it was the finest object of the kind since 1861. . . . It was at first thought by northern

astronomers that this apparition was a return of the great comet of 1807, but this question has been decided in the negative by Dr J. Priem's definite investigation in 1894." [1]

While sweeping for comets with the 3¼-in. refractor on the evening of September 17, 1881, Mr Tebbutt found a small nebulous object in the constellation Libra. It did not exhibit a tail, but its apparent motion soon proved it to be a comet. Shortly after the discovery, news arrived from Europe that the comet had already been discovered by Mr Schaeberle, of Ann Arbor Observatory, U.S.A., on July 14. In 1882, on September 8, Mr Tebbutt received a telegram from the Goverment Astronomer at Melbourne to the effect that a large comet had been reported due east at 4 o'clock in the morning. Other messages were received during the day from different parts of the Colony, and from the information thus received Mr Tebbutt was enabled to get observations on the mornings of the 9th and 10th, civil time. He tells us that "the nucleus was very large and remarkably brilliant, and the tail about 3° in length." For some days cloudy weather prevented further observation. Considering the apparent track of the comet as laid down from observations made, Mr Tebbutt suggested, in a letter dated September 16, "that there might be a transit of the comet across the sun's disc, and that a watch should be kept

[1] "Astronomical Memoirs," pp. 48-51, by John Tebbutt.

for so unusual a phenomenon. My communication was subsequently copied into *Nature*, of November 16, 1882. It turned out that there was a transit, but not visible in New South Wales. The entry of the comet's nucleus on the sun's disc was actually observed by Dr Elkin and Mr Finlay at the Royal Observatory, Cape of Good Hope. After contact the comet became invisible in consequence of the superior brilliancy of the sun's disc."

Mr Tebbutt made the first naked-eye observation of this comet in full daylight, the next being made at the Government Observatory, Melbourne. He tells us that "Dr A. A. Common, of Ealing, England, was, I believe, the first in that country to find the comet in full daylight, but his observation was about eleven hours of absolute time later than that made at Windsor. The comet exceeded in brilliancy any other I have ever seen, and was observed at numerous stations till June 1 of the following year." [1]

On December 2 and 8 observations of Comet III., 1882 (Barnard), were obtained in high south declination, but it was very faint. The Cape of Good Hope and Windsor were the only southern stations at which it was observed. In 1884 a small comet was discovered by Mr David Ross at Elsternwick, near Melbourne, Victoria, on

[1] During a visit to the Windsor Observatory in 1912 the writer was shown books containing the records of fifty-five observations of the comet of 1882, extending from September 8 of that year to March 2, 1883.—M.P.

January 7. It was found at Windsor on January 19, and was observed from that date till February 2, with the square bar micrometer on the 4½-in equatorial. According to the elements which Mr Tebbutt computed for it from these positions, "it passed its perihelion on December 25, 1883, at a distance of 29,000,000 miles from the sun, and was a new comet. It was observed at Madras, Melbourne, and Windsor only, and orbits were also computed for it by Bryant, Ellery, Oppenheim, and Tennant." [1]

"An extremely faint comet was picked up by Mr Brooks, of Phelps, U.S.A., on September 1, 1883, in the constellation Draco. When it had been sufficiently observed, a parabolic orbit was computed for it, but it at once became evident that the new visitor was no other than the expected comet of 1812. This interesting object, after a voyage of a little over 72 years through space, was watched with the greatest enthusiasm. After being well observed in Europe and the United States, it became visible in the Southern Hemisphere, where Mr Tebbutt observed it on every possible opportunity by means of the 4½-in. equatorial till April 1." [1]

On July 16, 1883, Mr E. Barnard (then at Nashville, U.S.A.) discovered a faint comet, and by the 24th, observations were begun by Mr Tebbutt and continued till August 22. His

[1] "Astronomical Memoirs," p. 60, by John Tebbutt.

observations were combined with those made at the Cape of Good Hope, Vienna, Arcetri, and Nice. They were adopted by Professor Egbert of Dudley Observatory, U.S.A., for a determination of elliptic elements which showed the comet to be a very interesting one of short period, namely, about 5·4 years. All the Windsor positions, together with those obtained at eighteen other observatories, were subsequently employed by Dr A. Berberich, of Berlin, in a definitive investigation of the orbit. (See *Astronomische Nachrichten*, vol. cxxiii.) The comet proved to have a period of only 1,972 days.

All these details have been given to show the value of linking up cometary observations, and how valiantly Mr Tebbutt did his share. In fact, his work had attracted so much attention that in 1882 he received a letter from the Scientific Society of Boston asking him to form an Australian Society of comet seekers similar to that in the United States.

" A club of this kind had existed for some years in that country, and nearly all the honours had been carried off by it in recent comet discovery. A considerable portion of the southern heavens was, however, shut out from the examination of northern observers, and for this reason the Boston Society recommended the formation of a comet corps in Australia. With kind words of encouragement from friends in England I proceeded to the task, but it was

unfortunately one which ended in disappointment. Although several gentlemen were possessed of telescopes adapted for the work, there was obviously a distaste for systematic observation." [1]

During 1886, Comet I. (Fabry) was observed on twenty-one nights, from May 2 to June 7; Comet II. (Barnard) on eight nights, from May 31 to July 1; and Comet V. (Brooks I.) on five nights, from July 3 to 21. Three comets were observed in the year 1888. The first, a bright one, was found by Sawerthal at the Royal Observatory of the Cape of Good Hope, on February 18.

"Copies of the ephemeris of Encke's well-known periodical comet, by Dr Backlund and Dr Seraphimoff, were received from St Petersburg on June 29 and July 5. The comet was found on the evening of June 8 by Mr Tebbutt, with the 4½-in. equatorial, almost exactly in the position assigned to it in the ephemeris. This is the fifth return of this comet which has been observed at Windsor. It appeared as a bright round nebulous star, uniformly condensed and about 1-in. in diameter. It rapidly became fainter, and difficult to observe. Positions were obtained on ten nights, extending from July 8 to August 1. The only other stations at which the comet was seen were the National Observatory at Cordoba and Royal Observatory, Cape of

[1] "Astronomical Memoirs," pp. 58-59, by John Tebbutt.

superposed on the star, I made four comparisons of this star with my comparison star of the preceding evening. The resulting position agrees to a minute of arc with that given in the ephemeris. Clouds prevented further comparisons so that I was unable to witness the subsequent separation of the comet from the star. No micrometric measures could be made of the diameter of the comet, but it could not certainly be less than 15″. Now as the distance of the comet from the earth at the time of observation was 57,000,000 miles, 15″ of arc would give a globular volume of cometary matter with a diameter of about 4,000 miles, and yet the star was well seen centrally through this mass. I may add that there is at least one instance on record in which the lustre of a fixed star has been increased by being viewed through the head of a comet, and there is yet another in which a star has been almost wholly obscured." [1]

"The fourth comet observed at Windsor in 1892 was that discovered by Brooks at Geneva, U.S.A., on August 28. After being well observed in the Northern Hemisphere it came south, and was observed at Windsor Observatory for the first time on the morning of November 29, civil time, and the observations were continued to the close of the year. In accordance with a request from Professor Krueger, of the Royal Observatory, Kiel, a search was made by Mr Tebbutt for Comet

[1] *Monthly Notices, R.A.S.*, p. 70, vol. liii.

of bright moonlight or haze, such was particularly the case on September 2, 7, 10, 11, 12; October 6, 7, 11, 25, 29. On October 25 it approached so close to star No. 59 as to be observed with the greatest difficulty."[1]

In 1889 a bright comet was discovered by Mr J. E. Davidson, of Queensland, and was observed at Windsor from July 23 to August 15. Comet Brooks V. was observed at Windsor on October 25 and 28, but Mr Tebbutt tells us, in his "Astronomical Memoirs," "it was a very faint and difficult object in the 8-in. telescope." In 1890 a search was repeated for Brorsen's comet, on January 18, 20, and 22, but without success. After January 22 the moon began to show in the west, so that it was useless to attempt a further search. "It appears," remarked Mr Tebbutt, "that the comet was carefully sought for by several northern observers, but with a similar result. I fear, therefore, that this comet, like that of Biela's, has been lost to science."[2]

In 1892 a Kiel cable message was received from Melbourne, on March 9, announcing the discovery by Dr L. Swift, at the Warner Observatory, Rochester, New York, of a bright comet on March 6, the news of the discovery reaching Mr Tebbutt on the evening of March 9. "The sky was cloudy on the following morning, and it

[1] *Monthly Notices, R.A.S.*, vol. xlvii., p. 293.
[2] "Astronomical Memoirs," p. 75, by John Tebbutt.

was not until the morning of the 11th that Mr Tebbutt succeeded in finding the stranger. From that date to April 23 inclusive, an excellent series of filar-micrometer measures in a bright field were obtained with the 8-in. equatorial. After May 2 the comet was too far north, but its observation was continued by northern observatories. Herr Berberich, of Berlin, found that observations extending over a period of four months can be satisfied by an elliptic orbit with a period of 20,000 years. The comet was visible to the naked eye from the time of its discovery till it ceased to be observed at Windsor. It passed its perihelion on April 7, 1892."[1]

The reappearance of Comet Pons-Winnecke was predicted for 1892 by Dr von Haerdtl (of the University of Innsbruck), who investigated the elements of the comet's motion for its various apparitions since its original discovery, and he also made an ephemeris for the use of intending observers.

"By means of this ephemeris the comet was found by Spitaler, at Vienna, on March 18, only about half a minute of arc distant from the theoretical position. It was picked up at Windsor on June 12, but as it was still unfavourably placed for southern observers, no observations were then attempted It passed its conjunction with the sun on July 7, and reached its nearest approximation to our planet on the 9th, being

[1] Read before the Royal Society, N.S.W., December 7, 1892.

then only 11,500,000 miles' distant. In consequence of this near approach it was more than usually brilliant in the telescope, and therefore admitted of very accurate observation. It was first observed here (Windsor) on the morning of July 18, civil time, and proved a morning object up to the end of August. Its positions were determined on twenty-four dates, extending from July 18 to September 27. These appear to be the only ones obtained after the comet's conjunction with the sun, and were employed by Hillebrand in 1897 for correcting the orbit and preparing an ephemeris for the return in that year. By this means Perrine was enabled to rediscover the comet at the Lick Observatory on January 2, 1898, within 4′ of the theoretical place."[1]

In the *Journal and Proceedings of the Royal Society, New South Wales*, Mr Tebbutt, after the above remarks about the Pons-Winnecke comet of 1892, wrote as follows: "I will conclude my notice of this comet by drawing attention to an interesting observation which I made on September 27, as it throws some light on the extreme tenuity of cometary matter. On looking for the comet on the night of September 27 to 28, in the position assigned to it in the ephemeris, I could not find it as a separate object, but a star of the 10th magnitude presented itself, fringed with a faint nebulous haze. As this was doubtless the comet

[1] "Astronomical Memoirs," pp. 79-80, by John Tebbutt.

superposed on the star, I made four comparison of this star with my comparison star of th preceding evening. The resulting position agree to a minute of arc with that given in th ephemeris. Clouds prevented further comparison so that I was unable to witness the subsequen separation of the comet from the star. No micro metric measures could be made of the diamete of the comet, but it could not certainly be les than 15″. Now as the distance of the comet fron the earth at the time of observation was 57,000,00 miles, 15″ of arc would give a globular volum of cometary matter with a diameter of abou 4,000 miles, and yet the star was well see centrally through this mass. I may add tha there is at least one instance on record in whic the lustre of a fixed star has been increased b being viewed through the head of a comet, an there is yet another in which a star has bee almost wholly obscured." [1]

"The fourth comet observed at Windsor i 1892 was that discovered by Brooks at Genev U.S.A., on August 28. After being well observe in the Northern Hemisphere it came south, an was observed at Windsor Observatory for th first time on the morning of November 29, civ time, and the observations were continued to th close of the year. In accordance with a reque from Professor Krueger, of the Royal Observator Kiel, a search was made by Mr Tebbutt for Com

[1] *Monthly Notices, R.A.S.*, p. 70, vol. liii.

Tempel (1), 1867 II., in the region indicated by M. Gautier's sweeping ephemeris, but without success." [1]

The year 1894 is memorable for the discovery of a comet by Mr Walter F. Gale, F.R.A.S., of Paddington, reported to the Windsor Observatory by telegraph on the forenoon of April 3, civil time. It was in the constellation Horologium. Mr Tebbutt found it on the evening of the former date with the 4½-in. equatorial. He sent a telegram announcing the name of the discoverer, the date of the discovery, and an approximate position to the Melbourne Observatory on the afternoon of the 4th for transmission by cable to Kiel. After the 4th the comet was well observed at Windsor with the large equatorial, the whole series of observations comprising twenty-seven nights, from April 3 to May 11, when it passed too far north for further work. At the time of Mr Tebbutt's last observation, May 11, the comet had receded to a distance of 101,000,000 miles from the sun and 41,000,000 from the earth. Its period of revolution round the sun is 1,143 years, according to H. A. Peck's investigation of the orbit of the comet, given in vol. xxi. of the *Astronomical Journal.* [2]

Photographs of this comet were taken by Professor E. E. Barnard, then a member of the staff at the Lick Observatory, California, but

[1] "Astronomical Memoirs," pp. 81-82, by John Tebbutt.
[2] *Ibid.*, p. 86, by John Tebbutt.

unfavourable weather prevented its being seen there until April 28. As Barnard tells us: "As this was a public night, and the observatory was crowded with visitors, no careful observations could be made of the comet. However, I got permission from the visitors to turn the 12-in. for a moment to its place, and found the comet at once. It was large, round, and condensed, with no trace of tail. Looking along the tube, I saw the comet was easily visible to the naked eye as a star of the 5th magnitude. The comet was certainly not a promising object for photography. On the night of April 29, however, I gave an exposure of one hour upon it with the 6-in. Willard portrait lens, and the comet was shown to have a very slender thread-like tail over 1° long. On this date no trace of a tail could be seen in the 12-in., or did an opportunity occur for getting another satisfactory photograph until May 2, when an exposure of 1 hour 15 mins. showed the tail distinctly for about 4°."

Other photographs were obtained on May 3, 4, and 5—the latter with an exposure of two hours and a half—but unfortunately the glass was so badly broken in transit that the photograph could not be reproduced.

"The peculiar characteristic of this comet was its slender tail and round head. There was no apparent development of the head as in comets usually possessed of a tail—that is, there was no

apparent diffusion of the material of the head to form the tail." [1]

In a paper on "Observations and Orbit-Elements of Comet Gale, 1894," by John Tebbutt, read before the Royal Society of New South Wales, July 4, 1894, a complete account is given not only of his observations but of the results with regard to the orbit-elements derived from them. It is forty years since Mr Gale made this, his first discovery of a comet, with a 3-in. telescope. It is now referred to as Comet 1894 II. Eighteen years later, on September 8, 1912, he discovered Comet 1912 II., an object of the 6th magnitude, visible to the naked eye. Again, in 1927, he discovered Comet 1927 VI., a comet of the 8th magnitude, which was detected with the aid of a pair of binoculars. This has a period slightly less than that of Jupiter, and can approach very close to that planet. At the February Annual Meeting of the R.A.S., 1935, the following remarks form part of an address on the award of the Jackson-Gwilt Medal to Mr W. F. Gale for his discoveries of comets and for his work for Astronomy in New South Wales:

"The discovery of as many as three comets by one individual implies many nights of assiduous observation over a long term of years. Mr Gale is to be congratulated on the successful outcome of his labours. The Council have added

[1] "Astronomy and Astro-Physics." Photographs of Gale's Comet, by E. E. Barnard, Mt. Hamilton, May 12, 1894.

as one of the grounds for their award the work done by the medallist for astronomy in New South Wales. Since 1886 Mr Gale has been an active amateur astronomer, and in 1894 he helped largely in the formation of the New South Wales branch of the British Astronomical Association. He was its first secretary, he served on its committees throughout, and he has acted as its president on several occasions. He has helped to popularise the science in New South Wales by numerous lectures, and he has maintained a spirit of friendly comradeship among observers in his own and neighbouring states in the Commonwealth of Australia."

The inaugural meeting for the establishment of a branch in connection with the British Astronomical Association took place in Sydney on January 30, 1895, when Mr John Tebbutt was elected as president. In his address he ascribed to Mr Walter F. Gale, of Paddington, the honour of initiating the steps which had led to the establishment of the New South Wales branch in connection with what he termed the "parent society" in England.

Mr Tebbutt continued his astronomical work, which he had begun in 1854, until 1904, when, having reached the age of seventy, he felt compelled to retire from systematic work. In the year 1905, at the annual meeting of the Royal Astronomical Society, held on February 10, the Jackson-Gwilt Gift and Medal of the Society

was bestowed on Mr Tebbutt "for his important observations of comets and double stars, and his long-continued services to astronomy in Australia, extending over forty years."

WILLIAM FREDERICK DENNING

William Frederick Denning, of Bristol, England, was one of the greatest amateur astronomers of modern times. As a lad he showed great interest in astronomy, and owned a 4¼-in. refractor when he was seventeen. About six years later he purchased a 10-in. refractor, with which he did most of his work. In 1869 he founded a Society for Young Amateur Observers, acting for a time as both secretary and treasurer. He contributed various notes to the *Astronomical Register* on different subjects, finally concentrating on astronomy as his life-work, and thereby obtaining world-wide renown.

His first contribution to the literature of the Royal Astronomical Society was made in 1872 (*Monthly Notices, R.A.S.*, vol. xxxiii., p. 93), through R. A. Proctor, as Denning was not then a Fellow. He described his observations of the Andromedid Meteors, and also his determination of the radiant. This keeps its place nearly unchanged during the whole continuance of the shower—for hours or days, it may be—and the shower is named according to the place of

the radiant among the constellations. Thus the meteors whose radiant is in the constellation Andromeda are named Andromede meteors. Like the comets, they pursue regular orbits round the sun, and the annual shower occurs at the point where the earth's orbit cuts the path of the particular swarm. Moreover, the earth reaches this point on the same date every year, the Andromedes following in the track of Biela's comet, of which they apparently form part of the débris. The Andromedes are due on November 24, and Mr Denning's record of this meteor shower is as follows :—

" *Andromedes.* Observed by Brandes, at Hamburg, December 7, 1798. It also recurred in 1838 ; the very brilliant showers of November 27, 1872 and 1885, are still fresh in the memory. It is uncertain whether this group forms an unbroken stream ; if so, the regions far removed from the parent comet must be extremely attenuated. Some of the meteors were seen in 1877 and 1879. The radiance is diffuse to the extent of 7° or 10°. Returns of the shower should be looked for in 1892 and 1898." [1]

They materialised as expected.

In April 1876 Mr Denning contributed a paper to the *Monthly Notices, R.A.S.*, in which he gave a list of twenty-seven radiant points of meteors he had observed. In May 1890 he supplied a list of 918 radiant points which he

[1] " Telescopic Work," p. 276, by W. F. Denning.

had deduced from 9,177 paths observed over seventeen years.

" His plan of work is of interest. Generally, he looked towards the east, sitting in a chair in mild weather, but when the nights were cold he either stood or paced up and down. On the subject of meteors he contributed many papers to different journals—*The Observatory*, *Nature*, *B.A.A. Journal*, *Knowledge*, and *Monthly Notices, R.A.S.* The last named, for November 1923, contains a catalogue of 314 radiants, found from his observations at Bristol, 1912-22 ; and in vol. liii. of the *R.A.S. Memoirs* there is a general catalogue of more than 4,000 radiants determined by himself and others." [1]

Dr Olivier pays a high tribute to Denning's meteoric work in *The Observatory*, October 1931. He says : " Probably his most outstanding discovery as to meteors was his final definite proof that the Perseid radiant moved from night to night. Once this was accepted, advances in many directions were possible. His calculations of the heights and paths of fireballs must have run into the hundreds, and his data will furnish indefinitely one of the richest mines for the theoretical investigator."

(In the *B.A.A. Journal*, vol. xlii., November 1931, we read : " He was a born observer, and one of the few in this country to have carried out systematic comet-sweeping. He was rewarded

[1] *Monthly Notices, R.A.S.*, vol. xcii., 1931-32, pp. 248-249.

by the discovery of five comets, which he estimated cost him on the average 119 hours of work each. In recognition of his work he was awarded the Valz Prize of the Academie des Sciences in 1895, and the Gold Medal of the R.A.S. in 1898.")

He tells us, in his "Telescopic Work for Starlight Evenings," how he missed discovering a comet on July 11, 1881. He had thoughts of sweeping the Auriga region with the aid of his comet eyepiece, but as the prospect did not seem very enticing, he gave up the idea. Only three nights later a bright telescopic comet in Auriga was discovered by Schaeberle, at Ann Arbor, Michigan. However, he profited by his experience on this occasion. In the same year, on October 4, after he had made some observations on Jupiter before sunrise, he hesitated about comet-sweeping, but, remembering his previous experience, he started sweeping, and almost immediately discovered a new object which afterwards proved to be a short-period comet, known as 1881 V. This was a telescopic comet in the constellation Leo.

"It was circular in form, about 1′ in diameter, with a slight central condensation. It soon became known that its orbit was elliptical, and its period about 8¼ years. It was expected to return in 1890, but was not found, the explanation perhaps being that the expected date of its perihelion passage indicated a path unfavourable for observation. As it could not be found in

1899 or in 1907, in both of which years it was due to return to perihelion, and as its orbit could not be determined very accurately in 1881 for the lack of sufficient observations, this comet must, for the present at least, be set down as 'lost.' The elements bear some resemblance to those of the comet 1819 IV., discovered by Blanpain. Winnecke suggested that the comet was seen by Goldschmidt at Paris in May 1855, and then regarded as perhaps Di Vico's, and Hind's comet 1846 IX., may both have been apparitions of Denning's comet, but it can only be said of this suggestion that it is at best a plausible one." [1]

In *The Observatory*, vol. lv., p. 331, there is a letter from Mr Denning, dated October 19, 1881, in which, after remarking that it was satisfactory to know that the comet seen by him on the morning of October 4 had been successfully observed at Marseilles, Dun Echt, and Harvard College, U.S.A., he makes the suggestion that English observers who, like himself, had the necessary time and instruments, should make some attempt "to enter into friendly competition with foreigners in the field of cometary discovery. It is certainly remarkable that we invariably allow the intimation of such discoveries to come from abroad. We might act in unison, and arrange a division of labour. Certain regions could be apportioned to different observers; in any case, it is very desirable to

[1] "The Story of the Comets," p. 85, by G. F. Chambers.

adopt some method likely to command the interest *and labour* of observers, and to give a fair measure of success."

In his advice regarding comet seeking, Mr Denning calls attention to the fact that the vicinity of the sun is the spot to which the comet-hunter should direct his chief attention, since it is here that the majority of discoveries have been made. Hence the most likely spots are over the western horizon after sunset, and the eastern horizon before sunrise. Nevertheless, he cautions the observer that other regions should not be altogether neglected, "for comets are occasionally found in nearly the opposite part of the heavens to the sun's place, as, for example, Zona's comet of November 1890. In order to save time, and to prevent troublesome references during the progress of sweeping, the brighter nebulæ should be marked upon a star-chart, so that as they enter the field they may be instantly identified."

"No observer should be without the means of determining exact positions. A ring-micrometer and comprehensive star catalogues are most important accessories of the amateur. When a suspicious object is found its precise position should be instantly measured; but if no micrometer [1] is at hand, the observer should carefully note the place relatively to adjoining stars, and there, after a short interval, re-observe it for

[1] A micrometer is an instrument for the measurement of small angles, etc.

traces of motion. In these comparisons the low-power eyepiece should be exchanged for one of greater amplification, because this will render a slight motion more readily sensible. If the suspicious object proves to be a comet, the extent and direction of its daily motion should be computed from the change in the observed places, and the information telegraphed to the Royal Observatory, Greenwich. A statement should also be given as to the diameter and brightness of the object ; we may then be satisfied that it will be readily picked up at some of the many stations where prompt attention is given to this class of observation. . . . There is a great necessity for the observer to have the means of measurement, and to utilise them during the first few observations, which are usually made before the comet has been seen elsewhere, and will therefore possess great value, if precise." [1]

Mr Denning's second periodical comet was discovered on March 26, 1894, in Leo Minor. It was a faint comet which was becoming fainter, because the perihelion passage had occurred about seven weeks earlier (February 9), and the comet was receding both from the sun and the earth. Its orbit was elliptic, and the period of about seven and a half years, but owing to the lack of an adequate number of observations definitive

[1] "Telescopic Work for Starlight Evenings," pp. 257-258, by W. F. Denning.

elements could not be assured. Now if only amateur observers had answered Mr Denning's suggestion, made in 1881, this comet would have given them a fine opportunity for furnishing the observations required.

"Schulhof called attention to the fact that the point of nearest approach between the orbits of the comet and Jupiter coincided very nearly with the point at which Brorsen's comet and Jupiter were nearest one another. The fact was further emphasised by Hind, who showed that the two comets were actually very near one another thirteen years previously, namely in April 1881. . . . Although expected to return in 1901, it was not seen in that year, nor in 1909." [1]

WILLIAM REID

The mantle of Denning seems to have fallen on the shoulders of William Reid, one of the greatest of South Africa's observational astronomers. William Reid came out to South Africa in 1901 and joined the firm of John Forrest & Co., Millers, of Rondebosch. His hobby was astronomy and his instrument a 4-in. refractor, later replaced by a fine photo-visual refractor. With these instruments he searched the sky for many hours night after night, during the course of his career. Every night on which observation was possible found him at the telescope, either during the

[1] "The Story of the Comets," p. 84, by W. F. Chambers.

first part of the night, or else from midnight until dawn. He was first and last an observational astronomer, and comets were his prey. At the B.A.A. Meeting, May 1926, he said: "I am often getting letters asking me to describe how I discover comets. There is only one way: go on looking for them. At first I used to find nebulæ a very great nuisance; they were for ever getting themselves mistaken for comets."

His desire to encourage others in searching for comets was so great that he undertook not to claim discovery of any comet found by himself if anyone else had communicated with him as to their discovery before he had reported to the Royal Observatory. In at least one instance he had actually announced to his friends that he had found a comet, and described its position and appearance some hours before a report reached him that it had already been detected by someone else.

As a result of his generosity the comet bears —not *his* name, but that of another amateur. How many of us would be willing to forgo the pleasure of being the first to discover the comet? Mr Reid was not only generous in this way but also extremely unwilling to talk about his work or read papers at the B.A.A. meetings. It was only occasionally one could induce him to give an account of the results of his own observations, combined with what he had read and studied in authoritative works.

He discovered six new comets and two periodic ones on their return (Encke and D'Arrest). The first was 1918 II. It was just a round nebulous object revolving in a parabolic orbit. His second comet was 1921 II. At perihelion it was nearly as bright as the 5th magnitude, and about a week earlier a train 40′ long had been photographed at Heidelberg. This comet passed within $4\frac{1}{2}°$ of the North Pole, and was under observation for eight months. Mr Reid's third discovery (1921 V.) was made in January 1922, but the comet had passed perihelion in the previous October. The fourth comet was 1924 I., discovered on March 30 of that year. During the time it was brightest it was invisible in Europe, but it was well observed in the Southern Hemisphere during six and a half months.

"The year 1925 has been justly described by Dr Crommelin as the *annus mirabilis* for comets, since it brought no less than eleven discoveries. . . . Of course, as was only right and fitting, Mr Reid had a share in the cometary discoveries of this wonderful year, finding 1925 III. on March 20. It was in perihelion four months later, and was altogether under observation for nearly two years. When brightest, it approached naked-eye visibility. Mr Merfield computed its orbit and found it elliptical, the period assigned being 6,910 years. Mr Reid's sixth comet, 1926 VII., had already passed perihelion when

he discovered it on January 21, 1927, and observations of it were confined to the Southern Hemisphere. Its orbit appears to be hyperbolic.

" This record of discoveries is an exceedingly fine one. Comets are not, as a rule, easy prey. There is, of course, always the possibility that a casual sweep with a telescope may bring a comet into the field of view—we remember that that remarkable object, comet 1892 III., was discovered by the late Mr Edwin Holmes when he was not looking for comets at all—but, generally speaking, such objects are captured only after a very great deal of persistent and patient searching.

" By his tale of discoveries, then, Mr Reid has brought much glory to observational astronomy in South Africa. Of course, it is not everyone—even though skilful in other ways—who can become a good observer, and certain special qualifications are needed to make a successful comet seeker. I have already hinted at the necessity for patience and perseverance, but the observer also must have a sensitive eye and the power of quick discrimination, as various objects flit across the field of his telescope. It is very easy to sweep over and miss so delicate an object as a faint comet. Mr Reid has remarked that his eye has become so sensitive to comets that he has sometimes picked them up in his sweeps when his friends could not see them even

though placed for them in the middle of the telescopic field." [1]

Mr Reid was awarded the Jackson-Gwilt Medal and Gift from the Royal Astronomical Society, at the Annual Meeting held in February 1928, at which the Address, from which the above is quoted, was made by the President, Rev. T. E. R. Phillips. Mr Reid's work gained him a position of honour among observers, and he was elected President of the Astronomical Society of South Africa on June 8, 1927, on which occasion he delivered the following address, during which he referred to the fact that the Society is composed of both professional and amateur astronomers distributed over the whole of the Union, Rhodesia, and South-West Africa. Soon after the Society was brought into working order he felt that an effort should be made to do some original work.

"The Comet Section has been under one Director from its inauguration. It has had a very successful career. We have now discovered fourteen new comets, and rediscovered two periodicals, one of which was supposed to be lost and the other was only seen by one observer at its apparition. We have also several independent discoveries to our credit.

"I have always been interested in comets, and have often been asked why. Perhaps the following reason may account for it to some

[1] *Monthly Notices*, vol. lxxxviii., pp. 347-348, February 1928.

extent; at least it will satisfy some people. A great comet was blazing high up in the northern heavens within half an hour of perihelion when I first saw the light.

"The first comet to leave an indelible impression on my young mind" (he was then thirteen years old) "was that of Coggia, 1874 III. This comet was an extraordinary phenomenon to me. It was very brilliant, with a long bright tail, the rapid growth of which one could almost visualise, and it disappeared as quickly as it had appeared. Since that time I have seen many great comets, many much brighter and bigger than Coggia, but none of them has left so great an impression on my mind as Coggia. Perhaps it may have been that it came at a time when my mind was beginning to grasp some of the truths of astronomy. Its sudden appearance, and the difficulty I experienced in understanding its movements, impressed me most vividly. I put Coggia down as the starting-point of my interest in comets. I have seen quite a number of extraordinary, and what one would call great comets, but I have not the time to describe them. From about the year 1879 to 1883 we had great comets every year, sometimes two could be seen at one time. Since then there have been very few, only the great comet of 1901 and Halley's.

"Comets are most mysterious objects, and even at the present time very little is known regarding their composition or origin. From

my own observations I have come to the conclusion that there is very little difference between comets and meteors. In all probability the meteors are wandering débris from the comets, and in the case of some of the large fireballs, they are comets which are all nucleus without any attendant companions. I saw both my last comets pass almost centrally between me and a star without the star losing any perceptible light. This would lead one to deduce that the head of a comet was composed of a swarm of particles, no doubt varying in size, and some of them sufficiently large to keep the whole together by the force of gravitation. When I rediscovered D'Arrest's comet, it looked, under a power of 216, like a compact cluster of very tiny scintillating stars. It was only under a very low power that it had the slightest appearance of haze. In 1872 the earth passed through the path of Biela's comet, and although we were a considerable distance from where the head of the comet was computed to have been, the particles were sufficiently numerous to give us a fine display of shooting stars.

"I could mention many other instances of a like nature which I have seen myself, but this is sufficient, I think, for us to conclude that the head of a comet is composed of a vast quantity of meteorites spread over a very large space, but in the majority of cases more condensed towards the centre. In a large comet I have no doubt

some of the particles may be of a large size. If the meteoric theory of the lunar craters is correct, I think the earth would come off very badly in an encounter with a really great comet. I am inclined to think that all comets belong to the Solar System, and that their paths are ellipses, in most cases tremendously elongated ellipses. So far, I do not think that any comet has been discovered travelling at a speed sufficient to enable it to get beyond the sun's influence. The Jupiter comets are generally supposed to have been caught by this great planet, but I incline to the theory that Jupiter is the parent of many of them—possibly all.

"It has been proved that comets have disintegrated and disappeared within living memory, and if this is the case with some, the process of disintegration may be going on in all. If so, we must provide some means whereby the number may be augmented. We see great changes taking place on the surface of Jupiter, and it may be that this is caused by great eruptions on the planet. I do not wish to carry this theory further, but it is a curious fact that the whole of the Jupiter comets travel round the sun in the same direction as the rotation of the planet on its axis. I can hardly imagine that this would be the case if they were all captures." [1]

In the same number of the *Journal*, p. 69,

[1] *Journal, Astronomical Society of South Africa*, October 1927. Extract from Presidential Address by Mr Reid for the Session 1925-26. Delivered on June 8, 1927.

is given an account of comet 1926 VII., the last discovered by Mr Reid, concerning which he wrote : " A new comet was discovered by the writer at Newlands, Cape Town, on the evening of January 25, 1927. This was a sister comet to comet 1927 II. (Blathwayt) in size, brightness, and physical appearance. It was kept under observation until the beginning of April. Before disappearing (which it did very rapidly) it swelled out to very large dimensions, at the same time becoming very faint, and losing all signs of the central condensation."

Comet 1927 VII. (Periodic Comet Pons-Winnecke) was discovered photographically at the Yerkes Observatory by Professor G. van Biesbroeck on March 3, 1927. It was then a small nebulosity, magnitude 16·5. In time it came rapidly south, and when first seen by Mr Reid it had become a very easy object, almost visible to the naked eye. It was still small but bright, and slightly elongated. With a low power it appeared to have a large nucleus, which had a curious striated and mottled appearance, with a fair amount of haze round it. Under a high power the haze disappeared but the nucleus did not differ very much from its former appearance. It would not come to a focus, and was rather disappointing ; one expected to see something definite. A few days later it became clearly visible to the naked eye as a large cloud of white haze. Through the telescope the nucleus had

become distinct, small, and very bright, surrounded by a great amount of nebulous haze which filled the whole field, and extended outwards until it faded imperceptibly from view. It had also developed a broad, short tail. Mr Forbes reported that in the second week in July the nucleus had become much larger, and had a granulated appearance. The tail also had become more distinct and longer, the comet itself having dwindled in size.

The Periodic Comet Grigg-Skjellerup 1927 V., photographed by F. T. Hargreaves, and detected on the plates by G. Merton on March 27, 1927, is also referred to in the Reports of the Comet Section for the year ending 1927, June 30, of the Astronomical Society of South Africa, as follows : " The comet appeared as a faint blur, and its magnitude was said to be 12. As at this time it was well placed for observers in South Africa, a thorough search was made for it, but without success. This comet at its last appearance was a faint diffuse object without any apparent nucleus, and it appears to have differed very little from this description at its last visit. Unfortunately, it was going north so quickly that it was soon outside our reach."

The new comet discovered by Walter Gale at Sydney, on June 7, 1927, was observed in South Africa soon after its discovery. Mr Reid describes it appearing " as a large and rather faint nebulous patch, round and condensed in the

centre, but without a nucleus. The nebulosity appeared to get faint from the centre outwards, and it was difficult to say where it ended. The magnitude was less than 8. When observed a few days later it appeared to be fainter.

"This is the third comet discovered by Mr Gale. It will be remembered that his second one was independently discovered in South Africa by Mr Skjellerup, and that the formation of the Cape Astronomical Association was the outcome of this discovery. This led to greater things, and now we have the Astronomical Society of South Africa."

Unfortunately, Mr Reid's splendid work at the Cape came to an end on June 8, 1928, when his death occurred at Rondebosch, Cape Peninsula. Dr Crommelin, as Director of the Comet Section of the B.A.A., referred at the June Meeting of the B.A.A., 1928, to the sad news of Mr Reid's death, and the great loss that cometary astronomy had sustained in his death, as follows: "He was the most assiduous comet searcher in the last decade. Comet sweeping is work that needs great patience and perseverance: one has to sweep many hours for each success. I receive numerous letters from people who propose to take up this work, and ask for hints about it. But I very seldom hear from them again, so that I fear most of them quickly tire of it. Mr Reid continued it for ten years, his first discovery being 1918 II. . . . He also aroused enthusiasm for the work

in others, and I understand that Skjellerup, Ensor, and Blathwayt, who also found comets, were influenced by him to take up the study. He was recently President of the Astronomical Society of South Africa, and his Presidential Address, delivered in June 1927, gives a good idea of the wide range of his astronomical interest. Members will remember seeing him here about two years ago, when he came to England in the hope (unfortunately not realised) of improving his health. On his return, in spite of illness, he succeeded in discovering another comet, 1926 VII., which will, I think, prove to have the most hyperbolic orbit on record.

"It is some consolation to know that the closing days of his life were cheered by the award, last February (1928), of the Jackson-Gwilt Medal and Gift from the Royal Astronomical Society."[1]

ALEXANDER FORBES-IRVINE FORBES

Alexander Forbes-Irvine Forbes took over the charge of cometary work at the Cape when Mr William Reid was compelled by ill-health to relinquish it in 1927. He has had the good fortune to begin his series of discoveries by the valuable rediscovery of Comet Pons-Coggia-Winnecke now known with the additional name of Forbes. This was a far more useful discovery than a mere parabolic comet would have been.

[1] *Journal, B.A.A.*, vol. xxxviii., pp. 246-247, June 1928.

The photograph of Forbes's Observatory at Blairythan, Hermanus, Cape of Good Hope, shows where he discovered this comet on November 19, 1928, at the end of an eight months' searching with an 8-in. reflector, an instrument of his own construction. Since then he has discovered two more comets, one of which is a short-period comet (period six and a half years), found in August 1929; return expected in November 1935. His third comet, found in May 1930, had an appreciably parabolic orbit. He has shown such energy and perseverance in his cometary work that Dr Jackson, the present Astronomer Royal at the Cape, on the occasion of his visit to England in May for the purpose of attending the International Astronomical Union, spoke of him at the May Meeting (1935) of the B.A.A. with the greatest enthusiasm. He described how Mr Forbes frequently gets up at 4 A.M. to sweep for comets, and stirs up other members of the Comet Section to do likewise.

Mr Forbes is now the Director both of the Comet Section and of the Zodiacal Light Section of the Astronomical Society of South Africa.

While on the subject of South African work, gratitude must be expressed to Mr H. E. Wood, Director of the Union Observatory, Johannesburg. He is persevering in obtaining accurate photographic positions of all southern comets. Most of the accurate positions of the Pons-Coggia-Winnecke-Forbes comet obtained in 1928 were

obtained by him and his assistants. Incidentally, the new comet 1934 II. observed by Mr Jackson has the large perihelion distance of 3·506 units, and as it was not found until nine and a half months after perihelion, it is now out near the orbit of Jupiter.

EDWARD EMERSON BARNARD

Edward Emerson Barnard, our R.A.S. Medallist, and therefore entitled to a place in this chapter, was born at Nashville, Tennessee, in 1857. His early education was limited to two months' attendance at school and such education as his mother could give him. Fatherless, at the close of the Civil War in U.S.A., he began at the age of eight or nine to work in a large photographic studio in Nashville, and soon became a reliable and accomplished assistant to his employers. A friend lent him Dr Dick's book, "The Practical Astronomer," in 1876, which awakened in him a great love for astronomy. The use of a 1-in. cheap lens, roughly mounted in a tube of his own construction, gave him some idea of what could be done with a telescope.

A travelling showman to Nashville, with a small glass for street exhibition, further stimulated him to acquire as good an instrument as he could for himself. By practising the most rigid economy he was enabled to purchase a 5-in. telescope, and his first systematic work of any

importance was a careful study of the planet Jupiter. In 1881 he began to search for new comets with his 5-in., and succeeded in discovering one on September 17 of that year. This was followed a year after by another, and in 1884 he found a comet of period 5·4 years. The next year, 1885, yielded two new comets ; 1886, one, and 1887, three more ; and in the five succeeding years he found altogether eleven comets, one of them (1892 V.) being another new comet of short period (6·30 years).

A great incentive for discovering new comets was offered in 1880 by Mr H. H. Warner, a wealthy American, who offered a prize of two hundred dollars for every unexpected comet found by an observer in Canada or U.S.A. Now it was in connection with this offer that E. E. Barnard distinguished himself as one of the most successful competitors. He had nineteen comets to his credit, resulting in the erection of what he quaintly termed : "The house that was built with comets."

"Times were hard," he tells us in a short autobiographical sketch, "in the last of the seventies and the first of the eighties, and money was scarce. It had taken all that I could save to buy my small telescope. I had been searching for comets for upward of a year with no success, when a prize of two hundred dollars for the discovery of each new comet was offered (in 1880) by the founder of the Warner Observatory

through the agency of Dr Lewis Swift, its Director. Soon after this it happened that I found a new comet, and was awarded the prize. Then came the question, 'What shall I do with the money?' After due deliberation it was decided that we" (referring to Mrs Barnard) "would try to get a home of our own therewith. I had always longed for such a home, where one could plant trees and watch them grow up and call them our own. So we bought a lot with part of the money, which was on rising ground selected in part because it gave me a clear horizon with my telescope.

"After some saving and mainly a mortgage on the lot, we built a little frame cottage where my mother, my wife and I went to live. Those were happy days, though the struggle for a livelihood was a hard one, working from early to late, and sitting up the rest of the twenty-four hours hunting for comets. We looked forward with dread to the meeting of the bills that must come due. However, when this happened, a faint comet was discovered, and the money went to meet the payments. The comets conveniently timed their appearance with the advent of those dreaded bills. And thus it finally came about that the house was built entirely of comets. True, it took several good-sized comets to do it, but it was done, nevertheless."

(In connection with the prize offered by Dr H. H. Warner, Professor W. H. Brooks discovered

twenty comets, Barnard nineteen, as already stated, Perrine thirteen, and Swift eleven. Awarding this prize was given up after a while, but the idea was again revived by a wealthy American, Mr J. M. Donohoe, in the year 1890, with the result that a bronze medal is now presented to the discoverer of any new comet, on the report of a Committee of the Astronomical Society of the Pacific. On November 10, 1923, Mr W. Reid, of Rondebosch, South Africa, was awarded several of the medals for his discoveries of comets.)

In 1888 Professor Barnard was offered a position at the Lick Observatory, then about to be opened, with the 36-in. equatorial, at that time the largest in the world. The able way in which he availed himself of the advantages of the wonderful Californian climate, of which he used to speak with an almost reverent enthusiasm, is now familiar matter of history. His knowledge of photography was invaluable. The astronomical photographs which he made were taken with the "Willard" lens of the Lick Observatory, having an aperture of 6 in. and a focal length of 31 in. His photographs of the Milky Way were the first to show its structure, and with regard to the comet photographs, he was the first to discover a comet by means of photography. The series of photographs taken by Professor Barnard, showing as they do the rapid changes that take place in the tails of comets,

are of great value. He also actually obtained meteor trails on photographic plates during 1890, on August 9, 10, and 11. On one of the plates of Brooks's comet, taken in 1893, November 13, there is a very fine trail of a meteor. In August 1889, he discovered four attendants of Brooks's comet. He followed faint comets long after they had become invisible in other instruments, notably Brooks' comet of 1889, which was observed by him nearly a year longer than by any other observer. A comet discovered by himself in 1888, he followed for over two years—the longest duration of visibility then known. He classified periodical comets by their visual appearance, so that on several occasions he was able to tell a short-period comet at the first glimpse in the telescope.

Professor Barnard left the Lick Observatory only to exchange work with the 36-in. refractor there for the 40-in. refractor at the Yerkes Observatory, Williams Bay, Wisconsin. Success followed success, and his discoveries brought him many honours. He received the Lalande Arago and Janssen Gold Medals from the French Academy, the Gold Medal of the Royal Astronomical Society, and the Bruce Gold Medal of the Astronomical Society of the Pacific. He was also awarded several university distinctions and degrees, but possessing as he did the true scientific spirit, he was not one to seek honours or to parade them. He was elected a Fellow of

the R.A.S. on February 13, 1888, and was made an Associate on December 9, 1898.[1]

NOTES ON THE LIVES OF COMET-HUNTING ASTRONOMERS

Jean Louis Pons (1761-1831), French astronomer, born at Peyre (Haut-Alpes), December 24, 1761. In 1789, when he was twenty-eight years old, he became a doorkeeper (concierge) of the Observatory at Marseilles, where the Director of the Observatory, St Jacques de Sylvabelle at first, and Thulis later on, gave him lessons in astronomy. It was through them that he acquired a European reputation by his discoveries of comets. He looked for them with telescopes constructed entirely by himself, and he also figured the lenses.

Appointed Assistant Astronomer in 1813, Pons went in 1819 to the Observatory at Lucca (in Italy) as Director; then to the Observatory at Florence, where he died on October 14, 1831. From 1801 to 1827 he discovered forty-five comets, of which eighteen were observed at Marseilles. He was nicknamed "Comet's Magnet."

The Lalande Prize of 600 livres was awarded to him by the Academy of Sciences at Paris.[2]

[1] See *Monthly Notices*, *R.A.S.*, vol. lxxxiv., p. 4, February 1924.

[2] Facts concerning Pons, kindly supplied by Professor Jean Bosler, present Director of the Observatory of Marseilles (Professeur à la Faculté des Sciences).

Regarding Encke's comet, which Pons discovered on November 26, 1818, the following quotation is from the "Life of Encke," p. 64:

"Encke invariably referred to this body as the Comet of Pons, adding that Pons had earned this title by having made two independent discoveries of it (in 1805 and in 1818). However, Bode and Olbers gave the comet the name of Encke, and this was used by everybody except Encke himself. Pons made no claim in the matter. He had found so many comets that he could well spare this one to Encke."

Jerome Eugène Coggia was born at Ajaccio in 1849. In 1866 he was admitted as a student at Marseilles Observatory, becoming an assistant there in 1868. He received further promotion of rank in 1873, and it was in this year that he found the comet which is now known as Pons-Coggia-Winnecke-Forbes, that had been found at the same observatory by Pons in 1818. Coggia found four other comets, and he is best known for the Great Comet of 1874. He was awarded medals for his discoveries of comets and minor planets.

Frederich August Theodore Winnecke was born in Hanover in 1835. He was made a Doctor of Philosophy at Berlin University in 1856, and in 1872 he was appointed Professor and Director of the Observatory of Strassburg. He was there when he made his discovery, in 1873, of Comet

Pons-Coggia-Winnecke-Forbes. He died at Bonn in 1897. Besides discovering comets he studied the behaviour of their tails, noticing that some tails showed oscillations like the swing of a pendulum. He rediscovered the Comet Pons-Winnecke in 1858, while at Bonn University. He made researches on its orbit, proving its identity with Pons' comet of 1819. He was again the first to see the comet on its return in 1869.

CLAUSEN, though not a comet discoverer, deserves mention for his laborious calculations of cometary perturbations. Thus, in "Viertelsjahrschrift," vol. vi. (1871), he traced the perturbations of Comet Pons-Winnecke from 1819 to 1858. He did similar work for Biela's comet, and some other comets. Accurate predictions of the returns of comets are impossible without laborious work of this kind, and those who undertake it deserve the thanks of astronomers.

CHAPTER VIII

THE CAPTURE THEORY OF COMETS

By R. A. Proctor

"ABOUT half a century ago R. A. Proctor pointed out that the theory of the capture of comets of short period by the giant planets involved many serious difficulties. There would not be enough close approaches of comets to Jupiter to provide it with such a large family of comets. This is still more the case than Proctor realised, since convincing proofs have been deduced that the life of these comets is short (of the order of a few centuries), so that the supply must be frequently replenished.

"Very few astronomers have supported Proctor's view, but *Astronomische Nachrichten*, No. 5826, contains a long paper by S. Vsessviatsky which reaches a similar conclusion, and extends the suggestion to include those of the minor planets that have orbits close to that of Jupiter. Many American astronomers favour the suggestion that minor planets are associated with comets in their origin. One of Proctor's arguments was based on the Leonid meteors.

Le Verrier had suggested that Tempel's comet, which formerly contained the meteors, made a near approach to Uranus in A.D. 126, and had its orbit changed from a parabola to an ellipse. Proctor pointed out that an extremely close approach to Uranus would be necessary, and that the cometary mass would need to be condensed to an extent far beyond what we observe in comets, otherwise different portions of it would experience different perturbations, whereas observation shows that the orbits of all meteors are nearly identical."

In connection with the above remarks by Dr A. C. D. Crommelin, which appeared in *Nature*, December 19, 1931, it may be of interest to give in its entirety an article by R. A. Proctor on the "Origin of Comets," which appeared in the *North American Review*, and later was published in *Knowledge*, August 8, 1884. The article is as follows :—

"ORIGIN OF COMETS

"We start from the conception that all comets originally entered our solar system ~~from without~~. They came, say Heis, Schiaparelli, and others who have advanced the Capture Theory, from out of interstellar space. Now it is no valid objection to this view that it gives us no idea how cometary matter came to exist in interstellar space, for in all inquiries into the past condition of the celestial bodies we must always come short

of their actual origin. Thus in considering the past of our solar system we may start from a chaotic vaporous state, or from a past condition in the form of cosmical dust, or from a condition in which the vaporous and the dust-like forms are combined, but if we are asked whence came the vapour or the cosmic dust, we are obliged to admit that we cannot tell. If hereafter we should be able to say that it came from such and such changes in a quantity of various forms of matter, which we may represent by X, Y, and Z, we should still be unable to say how X, Y, and Z came into existence. So that I make no serious exception against the supposed origin of comets on the ground that it really leaves very much to be explained. Interstellar space is a convenient place to which to assign the origin of bodies so mysterious as comets. *Cela exprime beaucoup de choses.* Almost anything might happen in regions of which we know so little, or rather of which we know absolutely nothing.

"Yet it may be worth while to remark that, on the whole, the interstellar regions are less likely to be the regions whence comets originally came to visit suns and sun systems than to be regions whither comets strayed after leaving originally the neighbourhood of solar systems. The most probable idea about the interstellar spaces is that they are the most vacuous regions within the range of the sidereal system. The mere circumstance that comets came from out of

them affords no better reason for regarding them as the original home of comets, than the circumstance that comets pass from the solar system into these interstellar spaces affords for rejecting that assumption. There is, in fact, simply no reason whatever for imagining that the place where comets came into existence is the vast unknown region around the solar system which we call interstellar space. Most comets come to us from thence; as many comets are travelling into that unknown region as are coming out of it. To form an opinion about the origin of comets from no better evidence than their last journey (out of millions, very likely [1]) can afford would be as absurd as for a day-fly to reason that the river flowing past the home of his race came out of the sky because a few drops of rain came thence.

"Suppose, however, we admit that in interplanetary space there have been in the past, and still exist, such flights of meteoric matter as the theory we are considering assumes. Let us grant them, also, such motion as may save them from what otherwise would inevitably be their fate, viz., a process of direct indrawing towards the nearest sun, and consequently destruction (with mischief probably to this orb), after a period of time which must be regarded as utterly insignifi-

[1] Comets lose so much of their substance at each approach to the sun that one cannot imagine such a long life for a comet as here suggested.—A. C. D. CROMMELIN.

cant compared with the time intervals measuring the duration of a solar system.

"It follows, then, that each flight of meteors would in the long run draw near some sun, without, however, rushing directly upon him; and sweeping round his globe upon such path as chanced to result from the combination of its original movement and its attractive influence, would pass out again into interstellar space. This might happen tens, hundreds, thousands, or even millions of times, a comet either sweeping in a long elliptical orbit with enormous periods of revolution, around one sun, or, if its velocity were slightly greater than that supposition implies, rushing first round one sun, then out into the depths of space to visit another sun, then to yet another, and so on, flitting from sun to sun for ever, or until the kind of disturbance in which the holders of the theory we are considering believe had changed this kind of motion into actual orbital circuit. (Only two kinds of cometic orbit are here considered, the elliptic and the hyperbolic; for a true parabolic orbit would be as unlikely, or rather as impossible, as a truly circular orbit among the planets.)

"In either case the minimum velocity with which a comet would be moving, when at any given distance from our sun would be determinable within a few yards per second. It is well known that the velocity with which a body travelling to the sun from an infinite distance (though

one cannot, of course, conceive such a movement) would reach the sun, would not exceed by a foot per second the velocity with which a body would reach him after travelling from the distance of the nearest fixed star. So, also, the velocities of bodies moving in orbits reaching half as far from the sun as the distance of the nearest star, would be the same within a foot or so per second as the velocities with which bodies coming to the sun from infinity would reach the same distance from him. If such bodies had originally a great inherent velocity, of course they would reach any given distance from the sun with much greater velocity. But this would not affect our estimate of the least velocity at that distance. Thus we know what the giant planets, to which has been attributed the final capture of those comets which now form a part of the solar system, had to do. We can tell the precise velocity in miles per second, or, at least, the minimum velocity, with which our imagined meteoric flight would cross the orbit of Neptune, or Uranus, or Saturn, or Jupiter, as the case might be, before its capture. We know, in the case of each comet supposed to have been captured, the precise velocity of the comet at the distance of the planet which captured it—its special planet master. The difference is the amount of velocity which the capturing planet had to take away in order to effect the supposed capture.

"Observe that we are here on sure ground, if

the theory is sound. It is certain that a comet coming from remote interstellar space to the solar system would have at the distance, say, of Jupiter, a certain velocity. It is certain that a comet now travelling in a particular orbit, approaching at one point very near to the orbit of Jupiter, has, at Jupiter's distance, a certain velocity, very much smaller. Hence it is certain that, if Jupiter captured that comet by disturbing it as it approached him on the last of its many free visits to the sun, the giant planet must have deprived the comet of so many miles per second of its former velocity. All we have to do is to find out how the planet could do this ; in other words, how near the comet must have approached the planet to be thus effectively disturbed.

"I have elsewhere (in a paper which appeared in the '*Proceedings*' *of the Astronomical Society*) given the details for certain cases which have been regarded as among the most satisfactory illustrations of the comet-capturing ways of the giant planets, and have shown that the theory is in those cases, and therefore in all, absolutely untenable, though so resolutely held. Still, it may be as well here to consider an illustrative general case—the simplest that can be taken and also the most effective, because the conditions are, in reality, much more favourable than they are in any known case.

"Imagine a flight of meteors to travel from interstellar space towards the sun until it reaches

the distance of Jupiter, and that when at that distance it chances to pass very close to the orbit of Jupiter, and at a time when Jupiter himself is very near the place where the meteor flight crosses his track. Observe that the chances against each one of these contingencies are enormous. If we conceive a sphere around the sun, girdled by Jupiter's orbit, the meteor flight in its course sunwards might traverse the surface of that sphere (or, which is the same thing, might traverse the part of its course where it is at the same distance as Jupiter from the sun) anywhere, and we are supposing that it traverses that surface close to a particular girdling circle (technically, a 'great circle' of the sphere). Suppose that by 'close' we mean within 1,000,000 miles, then the imaginary girdle of the sphere through which the meteor flight must pass to fulfil the required conditions is 2,000,000 miles broad. The sphere itself has a diameter of some 960,000,000 miles, and by a well-known property of the sphere,[1] its surface is 480 times greater than that of the girdling strip. The chance is but one in 480 that any meteor flight coming from interstellar space toward the sun will be within 1,000,000 miles of Jupiter's orbit when at Jupiter's distance from the sun. Then Jupiter's path has a circuit of more than 3,000,000,000 miles. Thus, the

[1] The property is this; that the surface of a sphere exceeds the surface of a girdling strip, such as we are considering, in the same degree (if the strip is relatively narrow) that the diameter of the sphere exceeds the breadth of the strip.

chance that at the moment of the meteor flight's passing the orbit, Jupiter will be within 1,000,000 miles on either side of the place of the passage, is as two in 3,000, or one in 1,500. But the chances that both these relations hold is only as one in 1,500 multiplied by 480, or as one in more than 700,000. Thus, assuming—though the case is otherwise—that 1,000,000 miles would be an approach near enough for capture, still only one meteor flight out of 700,000 which come from outer space could be captured by Jupiter.

"This, however, is but the mere beginning. We may admit that millions of times as many comets or meteor flights approach our system as the planets have captured, and if so, we need recognise no special force in any such considerations as have just been presented. I have only advanced them to suggest the conditions which are, as it were, essential for the process of comet capturing by a giant planet.

[1] "Arrived at Jupiter's distance from the sun, the meteor flight from interstellar space will have a velocity of about eleven miles per second. Now let us inquire what its velocity must be reduced to in order that it may thenceforth be compelled to travel in a circle around the sun. As a matter of fact, all the members of Jupiter's comet-family travel in orbits whose remotest parts are near Jupiter's orbit, and to give a comet such an orbit

[1] *Knowledge*, vol. vi., p. 126. "The Capture Theory of Comets," by R. A. Proctor.

as one of these, much more must be done in the way of reducing velocity than is necessary merely to make the meteor flight from outer space travel thenceforth in a circle at Jupiter's mean distance. We are taking, in fact, a very unfavourable case for our argument. Still, the velocity must be reduced, even in this case, by nearly three-tenths, or by more than three miles per second.

"Now Jupiter's power to withdraw velocity from a body in his neighbourhood is measured by his power to impart velocity. In fact, both processes are but different forms of the same kind of work. Precisely as we say that the sun can communicate a velocity of 382 miles per second to a body approaching him from interstellar distances, and that therefore the sun can withdraw such velocity from a body leaving his surface at that rate, and eventually bring such a body to rest out yonder in interstellar space, so can we make a corresponding statement for any planet—Jupiter or Saturn, the Earth, our Moon, and even for the least of all, the asteroidal family (supposing only the mass and size are known). In the case of Jupiter, for instance, we find that the utmost velocity he can impart to a body reaching him from external space is about thirty-six miles per second. That, at least, is the velocity with which such a body would reach the visible surface of the planet. What the velocity might be with which the real surface, far down below the visible envelope of clouds, would

be reached, we do not know—not knowing where that surface lies. In the case of our own earth, the velocity with which a body would reach the surface, if brought thither solely by the earth's action from interstellar space, would be a little over seven miles per second, or more than twenty-seven times greater than the velocity of the swiftest cannon-ball.

"But while Jupiter—to keep for the moment to our giant planet—has thus, theoretically, the power of giving or taking away a velocity of thirty-six miles per second, he is not practically able to do anything of the sort. He is not left to draw matter to himself, or to act on the recession of matter from himself, alone. The bodies which come near to him from outer space have been drawn by solar might within that distance from the sun, and almost the whole velocity they there possess is sun-imparted. We have seen what it is—some eleven miles per second. Now manifestly, this greatly affects Jupiter's power of imparting or withdrawing velocity. Both processes require time, and it is clearly impossible for Jupiter to produce anything like the same effect on a body rushing past him with a sun-imparted velocity of eleven miles per second as he would produce on a body left undisturbed to his own attraction. Jupiter's action at any moment is the same amount whether the body is moving or at rest; but the number of moments is very much reduced owing to the swift rush of the body past the planet.

To use the old-fashioned expression of the first students of gravitation (an expression which has always seemed to me amusingly quaint), the solicitations of Jupiter's attractive force are as urgent on a swiftly rushing body as on one at rest; but if a body will not stay to hearken to them, much less effect must be produced. In all this part of my reasoning, I may remark, I am not pleading a cause, but indicating what every student of celestial dynamics knows.

"We may fairly regard twenty-five miles per second as the utmost velocity that Jupiter can impart or take from any body coming out of interplanetary space past him, as close as such a body can pass without being actually captured. Moreover, in every possible case, Jupiter can only abstract or add a small portion of this amount; for this reason, simply, that in every possible case there will be first an action of one kind (addition or abstraction of velocity), and afterwards an action of the opposite kind (abstraction or addition respectively). It will be but the difference between these effects, in most cases very nearly equal, which will actually tell on the body's future period of revolution round the sun.[1] This makes an enormous reduction on Jupiter's potency to modify cometic revolution. Certainly ten miles per second is a very full estimate of the

[1] As distinguished from the orbit. The orbit might be largely affected even in a case where the velocity of Jupiter's distance remained absolutely unchanged; but in this case the period of revolution would remain the same.

velocity he can abstract or add in the case of a body passing quite close to his apparent surface.

"But even this may seem ample. Seeing that a loss of three miles or so per second would cause a body which had reached Jupiter's distance from the sun, after a journey from out of interplanetary space, to travel in the same period around the sun as Jupiter himself, and since we seem to recognise a power in Jupiter to abstract ten miles per second, it would seem as though Jupiter's capturing power were in fact demonstrated.

"But while, to begin with, the close approach required for this capturing power to exist is something very different from that approach within 1,000,000 miles which I before considered, there is a much more important difficulty to be considered, in the circumstance that we have thus far dealt with Jupiter's capturing power on one body, not on a flight of bodies, such as a comet approaching from interstellar space is held to be, according to the theory I am discussing.

"Let us take the former point, though the least important, first. At Jupiter's apparent surface the actual maximum velocity which the planet could give to a body approaching from a practically infinite distance would be about thirty-six miles per second, and we reduced the actual maximum effect on a body passing Jupiter very close, under such conditions as actually prevail in the solar system, to ten miles per second. Let us see what would be the corresponding

numbers in the case of a body passing within 1,000,000 miles of him, remembering that even that would carry such a body right through Jupiter's system of satellites, the span of that system being about 4,500,000 miles. Since a distance of 1,000,000 miles exceeds the distance of Jupiter's surface from his centre nearly twenty-five times, it follows (I need not explain why, mathematicians will know; and for non-mathematicians the explanations would be tedious and difficult) that the velocities which Jupiter can give or abstract at the greater distance would all be reduced to little more than one-fifth those determined for Jupiter's surface. So, instead of ten miles per second we should get but two miles per second as the greatest Jupiter could abstract from a body approaching him within 1,000,000 miles. And this would not be sufficient reduction to make such a body travel thenceforth in Jupiter's period, still less in one of the much shorter periods observed throughout what has been called Jupiter's comet-family.

"But the other difficulty is altogether more serious. A comet approaches Jupiter, on the theory we are dealing with, and indeed the same may be assumed on any theory, as a flight of scattered bodies. Either this flight is so close as to be in effect, because of mutual attractions, a single body, or it is not. If it is, the flight will not be broken up by Jupiter's action; and, if not so broken up, will remain for ever after a united

family. But if, as is more in accordance with observed facts, the cometic flight is so large that the attraction of the flight, as a whole, on the separate members, can be overcome by Jupiter's action, then not only will the flight be broken up, but the orbits given to different members of it by Jupiter's disturbing action will be widely different. Suppose, for example, the extent of the flight to be such that the parts coming nearest to Jupiter approach his centre within 50,000 miles (a very close approach, indeed, to his surface), while those parts which are remotest from him at the time when the flight, as a whole, is nearest, came only within 60,000 miles from his centre. Then, in round figures, the reduction of velocity of the nearer members of the flight will be greater than the reduction for the farther members, as six exceeds five. Supposing, for argument's sake, the former reduction to be three miles per second, as it must be to make those members of the flight travel thenceforth in Jupiter's period round the sun, then the reduction for the outermost members would be but two and a half miles per second, or thenceforth one set of meteors formerly belonging to the comet would have—at Jupiter's distance—a velocity of eight miles per second (eleven less three), while another set would have a velocity of eight and a half miles per second (eleven less two and a half) at that distance. This means that thenceforth the mean distance of the latter set from the sun would exceed the

mean distance of the former set about as nine exceeds eight.[1]

" Since the former set would thenceforth be travelling at Jupiter's distance, or about 5·2 times the earth's, the latter set would be travelling at a mean distance greater by one-eighth of this, or 0·65 of the earth's distance, say some 60,000,000 miles. The latter set would be at their nearest to the sun when at Jupiter's distance, would pass 60,000,000 miles farther away to their mean distance, and as much farther away still at their greatest distance. Practically, then, even in this case, as favourable for capture as can be well imagined, the capture, though effected, would result in spreading out the comet, which had arrived as a compact flight of meteors 10,000 miles only in span, over a region 120,000,000 miles broad. It is hardly necessary to say that nothing like this is observed in the case of any member of Jupiter's comet-family. We know that along their track meteors are strewn to distances which, in some cases, may well exceed even the enormous distance just named; but they lie along the track, not ranging more than a few 100,000 miles on either side from the path of the comet's head. This means that the orbit of every single meteor of such a system has, practically, the same mean distance from the sun.

[1] The simple law is, that for two bodies having different velocities at the same distance from the sun, the mean distances from him differ as the square of these velocities. Now the square of eight and a half is seventy-two and a quarter, that of eight is sixty-four.

"The difficulty last considered is simply fatal to the theory that the comets forming what has been called the comet-families of the giant planets were captured by those orbs in the way imagined by Heis, Schiaparelli, and others."[1]

THE ORIGIN AND NATURE OF COMETS

By A. C. D. Crommelin

Extract from *Scientia*, vol. vii. (1910) XXIV-2 (followed by Addendum to the above, written 1935).

I do not think that the time has yet arrived when we can give a complete solution of the problems of the nature and origin of comets. Considerable progress has, however, been made in this direction during the last half-century, and it seems worth while to collect and put in order some considerations which at all events limit the field within which the solutions must lie; this limitation is really a help to us in framing hypotheses, since it enables us to eliminate those that have little chance of proving fruitful.

It is now about fifteen years since M. Fabry published an essay concerning the true significance of the parabolic form in cometary orbits. The essay does not seem to be very widely known, as

[1] *Knowledge*, vol. vi., pp. 126-128.

is shown by the fact that Professor C. L. Poor, in the "Solar System," p. 281, argues as if the prevalence of parabolic orbits shows that the majority of comets come to the solar system from outside. In reality, as M. Fabry shows, if comets really came to our system from outside, quite a large number would have strongly marked hyperbolic orbits. It is easy to see that this is so if we reflect that the velocity at any point of a parabolic orbit is the same as that due to a fall from an infinite distance (or, practically, from any distance that is very great compared with the actual distance of the body from the sun) under the influence of the sun's attraction ; for a hyperbolic orbit the speed is greater than this, for an elliptical orbit, less. Hence to assert that a comet moving in an apparently parabolic orbit has come to our system from outside is equivalent to saying that it entered the sun's sphere of influence (by which we mean the region where the sun's influence is paramount, and to which we may assign an arbitrary radius, such as 1,000 times the radius of Neptune's orbit) with zero relative velocity ; in other words, it was previously moving through space with exactly the same motion as the translational drift of the solar system. The chances are slight of this being the case in a single instance, and it is out of the question that any considerable number of the comets whose orbits are sensibly parabolic should have reached our system from outside. The relative velocities of the stars are of

the order of many kilometres per second, which would suffice to produce an orbit of most markedly hyperbolic character in a comet reaching us from another system.

It is then clear that it is to our own system that we must look for the origin of the comets with apparently parabolic paths, and still more those of elliptical character. Within this system there are three different modes of origin that have been suggested: (1) that they are the products of eruptions from the sun; (2) that they are the products of eruptions from the larger planets in a sunlike state; (3) that they are stray fragments of the nebula which is supposed to have been the parent of our system, and that they remained unattached to any of the large masses that were formed from the nebula.

There are two points that are in favour of the solar origin: first, we can see, in the solar prominences, eruptions of gas at sufficient velocities to carry some of the projected matter away from the sun; secondly, comets by their spectrum, and meteors by actual analysis, reveal the presence of large amounts of hydrogen and its compounds, suggesting their origin in an atmosphere like that of the sun. The obvious drawback to this theory is that all matter ejected by the sun would travel in orbits intersecting his globe, and so if their speed of ejection was less than 383 miles per second (the parabolic velocity) they would on their return fall back on the sun. Planetary

perturbations might suffice to avert this, and produce an orbit just clearing his surface. We have instances of such orbits in the remarkable group of comets of 1680, 1843, 1880, 1882, and 1887, and a solar origin does not seem impossible for these; but there are many other comets whose perihelion distance equals or even greatly exceeds the earth's distance from the sun, and we can hardly suppose, without straining probabilities, that these changes were entirely produced by perturbations. There is a further difficulty in the way of the solar origin; the ejected matter would leave the sun in the form of vapour, and would only liquefy and solidify when it reached outer space. Probably it would solidify into particles of extreme minuteness, very much smaller than the meteoric masses that enter our atmosphere, many of which are known to have a connection with comets.

We turn next to the giant planets as possible comet-producers. The late Mr R. A. Proctor warmly advocated the view that the giant planets were the actual parents of the comet-families which are attached to them. Jupiter has a large and ever-growing family of comets which obviously owe him allegiance, since in the case of Lexell's and Brooks's comets he has been caught in the act of profoundly modifying their orbits; Saturn has two, of which Tuttle's has been observed at several returns; Uranus two, one being the comet of the November meteors; and there are six whose orbits are associated with

Neptune's in such a way as to suggest a connection. Three of these have been observed in two or more revolutions, one being the famous comet of Halley, which has been traced with tolerable certainty back to 240 B.C., and with some probability to 467 and 625 B.C. We have to go back to very remote antiquity to find a time when Neptune could have exerted any considerable influence on Halley's comet ; at present there is no near approach of their orbits, and Neptune's influence is trifling.

Proctor argued (1) that very close approaches to the giant planets would be required for their orbits to be transformed from an approximately parabolic form to an ellipse with a period half that of the planet, hence, (2), that the number of captured comets would be a very small fraction of the total number that approach the sun. It would require an immense period to produce such a number of comets attached to the various groups. The suggestion has been made that the number might be greatly increased by the consideration that comets that have their orbits changed into ellipses, even of long period, would sooner or later make other approaches to the planet, and might undergo further shortening. But I doubt whether there is much weight in this consideration, for the action of Jupiter is just as likely to increase as to diminish the period, and in only a few cases would the successive perturbations be all in the same direction.

On the other hand, if the planets be regarded as themselves the parents of these comets, their orbits would necessarily pass through the point of ejection, and consequently the difficulty (2) disappears. The only difficulty is the question whether the giant planets are now in a physical condition capable of expelling matter with a velocity of several miles per second. I do not think that we can put back the epoch of ejection to a date several million years ago, when the giant planets may have been in a quasi-sunlike state; for the life of a short-period comet seems to be measured by centuries, not by millions of years. In the last 130 years Lexell's and Brooks's comets have had their orbits greatly modified; two others, Biela's and Brorsen's, have definitely perished; while Encke's comet was extremely faint in 1908, which may indicate its approaching dissolution; to these we may perhaps add the numerous comets for which short periods have been found but which have never been seen again.

The conclusion is plain that if the giant planets are the parents of their comet-families, they must be, at the present time, capable of ejecting them. It does not appear to me that the possibility of such ejection can be summarily rejected. We have evidence of disturbances of intense violence in the Jovian atmosphere; the great red spot denotes a mighty cataclysm. Also the long rows of white spots that occur on Jupiter seem to indicate a series of eruptions far below;

there are occasional outbursts of white spots on Saturn. Moreover, there is no reason to suppose that the ejection of comets is a common phenomenon ; one ejection per century would probably suffice to balance the loss from dissipation and perturbation. Even on the earth we have occasional volcanic outbursts of extraordinary violence, as Skaptar Jokull in 1783, Krakatoa in 1883, etc. ; paroxysmal outbursts on a far grander scale may be expected on the giant planets. In 1883 it was computed that over a cubic mile of solid matter was blown to a height of many miles. This is probably comparable with the total mass of the smaller comets. A difficulty has been raised that the ejection of the matter would take some hours, in which case the rotation of the planets would greatly alter the direction of projection. I do not think there is much in this objection, as, if the whole mass of a small comet were concentrated into a compact form, it would not occupy many cubic miles, and its ejection might be practically instantaneous. In fact, there is less difficulty in this than in supposing that if the comet came from regions outside the planetary system, and was merely captured by the planet, it should be sufficiently small and compact for all parts of it to suffer the same perturbations. For a very close appulse is required for capture, and if the comet were a few thousand miles in diameter the perturbations of different parts would be sensibly different.

In discussing the solar origin of comets we pointed out the difficulty of conceiving how the ejected matter could form such large masses of iron as we find in meteors. The difficulty would be less in the case of the planets, the temperature being probably low enough for iron to assume a solid form quite close to their surfaces.

I conclude from all this that the hypothesis of the planetary origin of short-period comets deserves consideration, and should not be dismissed so summarily as it is by many astronomers.

Bredichin has given a different hypothesis for the origin of the short-period comets in his pamphlet "Sur l'origine des Comètes periodiques," Moscow, 1889. He supposes that they have simply arisen from the splitting up of larger comets, on the analogy of Biela's comet, that of Liais in 1860, of the Great Comet of 1882, and Brooks's comet in 1889. But in none of these cases is there evidence of notable alteration in the period, nor does the theory explain in any way the relation of the orbits to those of the four giant planets.

The third hypothesis of the origin of comets is that they are unattached outlying fragments of the nebula, which is conjectured to have been the parent of the solar system. I consider that we are practically driven to this theory by exclusion in the case of those comets whose perihelion distance is large and which do not belong to the planetary families. Seeing that comets have a large amount of meteoric matter associated with them, we

must assume a meteoric rather than a purely gaseous nebula.

Meteors are such complex bodies both in structure and composition that it is difficult to conceive of them as the primitive form of matter; they are more like the débris of earlier worlds. This idea naturally leads us on to the planetesimal hypothesis which has been lately put forward by Professors Moulton and Chamberlin. According to this view, the sun existed in past ages in solitary state, without any attendant worlds; at some very remote epoch another sun is supposed to have passed extremely near it, without actually colliding, but causing immense tidal disturbance by which an appreciable fraction of its total mass was torn off: 1/700 of its mass went into the known planets, a much larger amount returned to the sun, but some remained unattached and formed our comets and meteor swarms. It was the perturbing action of the other sun that gave the ejected mass moment of momentum, and thus prevented it from falling back on the sun. If we suppose that before the cataclysm our sun had already cooled sufficiently for a solid crust to form which would absorb a portion of the hydrogen and other gases in the atmosphere, we seem to get an explanation of the large solid meteoric masses that frequently fall on the earth and which contain a large quantity of occluded gases. The theory, of course, implies that the sun's temperature was again raised as a result of the

appulse, either by actual collision or the impact of the return of part of the ejected matter.

The chief drawback to the adoption of the planetesimal hypothesis seems to me to be the extreme improbability of such a near approach of two suns to each other. The interstellar distances are so immense compared with the size of each sun that such encounters must be excessively rare. The frequent appearance of Novæ is sometimes quoted as evidence in favour of such appulses; these outbursts occur, almost without exception, within the Galaxy, where we have good reasons for supposing the star-density to be much greater than elsewhere. Moreover, the very rapid decline in the light of Novæ suggests that they are not stars in an advanced stage of condensation but are in a much more diffused and tenuous state. On account of these difficulties I think that we should only regard the planetesimal hypothesis as a plausible conjecture, not as an established conclusion.

Passing on now to the question of the nature of comets, I assume as established that they all have as their nucleus a more or less dense swarm of meteors. This conclusion rests partly on the clearly proved connection of the Leonid, Perseid, and Andromedid systems with the comets of 1866, 1862, and Biela's comet, partly on the impossibility of conceiving that such comets as Halley's could persist for so many returns if they were mere bunches of vapour. According to the generally

accepted views of Dr Johnstone Stoney, even the moon and the smaller planets are incapable of permanently retaining atmospheres, in consequence of the rapid motion of the gaseous molecules. Since we are certain that the mass of Halley's comet is much less than that of the moon, it is evident that its gravitational power would be too weak to hold it together if wholly gaseous. It is probable that the meteors are continually giving off small quantities of gas (at least while in the neighbourhood of the sun), since otherwise we should expect the vaporous envelope to be dissipated with fair rapidity. The fact that Halley's comet has been emitting such large tails at every return for at least 2,000 years makes it probable that in its case the meteoric masses are of considerable size, perhaps larger than the large masses in our museums, since these must have suffered loss in their passage through the air. For we should expect small lumps, under a foot in diameter, to give up their whole supply of gas at a single apparition.

I put forward here the conjecture that, since it is only near perihelion that the loss of gas occurs, a large periodic time is favourable to a long life of the comet; hence the prevalence of nearly parabolic orbits may be a case of "survival of the fittest," the comets with shorter periods having already exhausted their supply of gas and therefore ceased to exist as visible comets. The disappearance of Biela's comet presumably means

only the loss of the gas contained in its meteors; these are still moving in the same orbit, as is shown by the many showers of Andromedids that have been observed since the comet disappeared.

I now pass to an independent proof of meteoric constitution of a comet's nucleus. This rests on the extremely close agreement between theory and observation in the date of the return of Halley's comet to perihelion. The calculation was based on the assumption that no forces were acting except the gravitation of known matter. The discordance amounts to three days at most, showing that any non-gravitational forces acting on the head are of the order of 1/10,000 of gravity.

But in the case of the tail the non-gravitational forces are predominant; further, the gases in the head are frequently almost indistinguishable in the spectroscope from those in the tail. If, then, the head contained nothing except these gases, it would move in the same manner as the tail does. The inference is plain that the head contains much denser matter, on which the influence of the tail-forming forces is inappreciable, and that this matter emits the gases which form the coma and tail. It seems certain that Halley's comet will transit the sun's disc about May 18·6, and it will be of interest to examine whether any trace of the comet on the sun can be detected. If so, it will enable us to form an estimate of the density of the head. The earth will probably pass through

the tail at the same time, as happened with the great comet of 1861. It is rather curious to reflect that even passing through the tail does not make it any easier to settle the question of its composition, for in all probability it is far too rarefied to have the slightest discernible effect on our atmosphere. A kind of auroral glow over the whole sky was suspected in 1861, and this should be looked for next May.

It only remains now to consider the question of the forces that produce thc tail. It does not seem necessary to invoke any other agency than the solar heat to explain the emission of gas from the meteors when the comet approaches perihelion. There are at least three theories to explain the repulsion of the tail from the sun: (1) Light-pressure; (2) Electrical repulsion; (3) Mechanical bombardment by electrons, or other tiny particles violently ejected from the sun. It is quite possible that all three act conjointly, as no one of them seems capable of explaining all the facts. The first and second, being central forces, could not alter the rate of description of areas of any particle of the comet about the sun. It is easy to deduce that tails produced by them would always start from the nucleus in the direction of the radius-vector produced. Now the photographs taken during the last few days give many instances of streamers leaving the head in directions making a considerable angle with this line. It seems clear that the forces producing these are

not wholly solar ; some expulsive force, for whose nature I can only suggest electrical repulsion, shoots particles violently from the head in various directions ; perhaps there is a slight favouring of the direction towards the sun, as we seem thus to get an explanation of the paraboloid envelopes so often seen on the sunward side of the nucleus, resembling the jet of a fountain. Morehouse's comet of 1908 showed these very distinctly, and they were discussed by Sir A. Eddington at the Royal Institution in 1909, March 26. He deduced a velocity of projection from the nucleus of 70,000 miles per hour, and a solar repulsive force 800 times gravity; a startling result, being far in excess of the values previously found by Bredichin or Jaegermann. Another point that shows that the tail-producing forces reside partly in the nucleus is the cycle of changes in the aspect of the tail that several comets, and notably Morehouse's, have shown. In the latter comet the Greenwich photographs revealed a fairly regular cycle that was many times repeated, so that it was even found possible, at the beginning of a cycle, to predict the subsequent behaviour. Since we cannot plausibly assign these short-period variations to any change in the solar action, we must suppose the source is in the nucleus.

Allied to the last are the numerous instances of apparent rotation of the tail, it appearing alternately broad and narrow, like a sword seen broadside and edgewise. Halley's comet showed

features of this kind in 1835, which were attributed by Bessel to rotation of the tail, in a period of about five days. There is a difficulty in supposing the tail to rotate, since this implies either a rigid body or a powerful central force to control the rotating particles, neither of which is present in the tail. A rotating head would, however, produce a semblance of rotation in the tail emitted by it. The conception of a rotating head involves the assumption that its separate meteoric masses are concentrated pretty densely, since they would not otherwise have sufficient mutual gravitation to control the rotation. The other cyclical variations of the tail, referred to above, also seem to involve concentration in the head, for if it was scattered over a wide area, it is difficult to see how the separate particles could all act in unison, as they appear to do.

Allusion should be made to the theory recently put forward both by Professor Newall and Mr G. Burns (possibly by others also) that the tail of a comet consists of matter already *in situ*, but in some way excited to luminosity by the passage of the comet. They point out that this would explain the similarity of spectrum shown by most comets' tails, and Professor Newall has found evidence of the presence of cyanogen in the interplanetary spaces. The idea of scattered gases is supported by the occasional shattering of comets' tails; instances are Brooks's comet, photographed by Barnard in 1893, and Morehouse's comet, on

October 15, 1908; there can scarcely be any doubt that the tail matter met some obstruction in space, which suddenly checked its onward movement.

But I find it difficult to believe that, at least, the beginning of the tail is not an emission from the head, since spectrograms with an objective prism frequently show head and tail absolutely continuous, so that it is not easy to say where the one passes into the other.

I pass now to the idea of the tail being due to the ejection of material particles from the sun. I think that Professor Schaeberle was the first to put forward this idea in 1893. He thought that both the corona and comets' tails are formed in this manner, his words in the *Astronomical Journal*, p. 306, being, "The tail of a comet is produced by the visible particles of matter originally forming the comet's atmosphere, and by the previously invisible particles of a coronal stream which, moving with great velocity, finally produce by repeated impact of the successive particles almost the same motions in the visible atmosphere of the comet as would be communicated by a continuously accelerating force directed away from the sun. . . . The coronal matter, owing to its retardation, grows so dense that it also becomes visible, and with the comet's atmosphere is finally driven into the tail by the repeated bombardment of unretarded following portions of the stream."

Since this was written, the radio-active elements have been discovered, and the theory of the dissociation of the atom into electrons has been adopted. Hence the particles suggested by Professor Newall and Mr G. Burns are much smaller than those suggested by Professor Schaeberle. Mr Burns (*Journal of British Astronomy*, xix., p. 5) says, " The radiant matter emitted by the sun is identical with the Beta rays given off by radium. . . . The impact of this radiant matter on the meteorites composing the comet's head generates light, and the spectrum of this light will be that of the atmosphere surrounding the meteorites. . . . We can account for the formation of the tail by the known property possessed by radiant matter acting as nuclei for the condensation of molecular aggregates. I suppose that as the particles of radiant matter from the sun pass through the head of a comet they collect matter round them, and become of sufficient size to reflect light." And Professor Newall wrote in the *Monthly Notices* for February 1909, " Is anyone who is familiar with the phenomena and theory of comets' tails prepared to say that the repulsion of these tails is not simply a phenomenon indicating the existence of this constant radial outstreaming of dust, rendered manifest by the glowing of the vapours set free by the nucleus of the comet, possibly under the influence of the incessant bombardment by the dust ? "

It is rather remarkable that these two passages

were written simultaneously, Mr Burns knowing nothing of Professor Newall's view. The idea of the bombardment by ultra-microscopical particles ejected from the sun is coming more and more to the fore to explain various phenomena in the solar system, in particular the corona, the aurora, and magnetic storms. In connection with the last, I recall Mr Maunder's papers in the *Monthly Notices*, in which he showed that the matter supposed to produce the storms was not projected equally from the sun in all directions but from definite areas in the sun (frequently marked by some notable spot or other disturbance) and outwards along definite streamlines, like the jet of water from a fireman's hose. For this reason I am not inclined to attribute the whole of the tail-phenomena of comets to this action, though I think it would be decidedly rash at the present time to deny its connection with special outbursts, such as those exhibited by Morehouse's comet, of which Sir A. Eddington said, "I am not sure that the exceptional activity of this comet is not due to the physical state of the sun at the time rather than to the constitution of the object itself."

We also recall Professor Backlund's discovery that the epochs of change in the rate of acceleration of Encke's comet coincided with times of maximum solar activity, and some reasons have lately been adduced for believing that the brightness of the same comet at different

apparitions also varies with the state of the sun's surface.

The electrical theory of the repulsion of tails explains the fact that the acceleration of some of the knots in the tail has been found to cease at a distance from the head which we may ascribe to a leakage of the charge. Also electrical excitement gives a more reasonable explanation of the glow of the gases in the tail than to suppose that they shine by actual incandescence, which can hardly occur except in the case of comets with very small perihelion distances.

To conclude, each of the three explanations of tail-repulsion seems to me to be a *vera causa* which we have good reason to believe is actually in operation; the only difficulty is to discriminate between the separate effects of each. This is work for the future; the rapid advance of cosmical physics in recent years gives ground for hope that the full solution is only a question of time.

GREENWICH.

ADDENDUM

This paper was written a quarter of a century ago, but further experience has only strengthened my belief in the views expressed in it. I think that the majority of astronomers now hold the view that the origin of comets is to be sought within the solar system and not in the stellar

regions. This view is decidedly strengthened by the researches of Professor Strömgren and his assistants on the perturbations of certain comets that had eccentricities slightly above unity at the time of perihelion passage. They computed the previous perturbations of the comet by the planets up to the time when the comet was well outside the planetary system, and found that in all cases the eccentricity was then less than unity, indicating an elliptical orbit. There is thus no proof from observation that any comet has entered the solar system with a hyperbolic orbit.

Professor Perrine many years ago put forward the suggestion that comets might be extremely numerous in the interstellar regions, and that only those that happened to have exactly the same motion as the sun would have the chance of entering the sphere of visibility ; others would pass too far from the sun for us to see them. As I showed in " Ency. Brit.," 14th edition, vol. vi., p. 103, this suggestion involves a fallacy; the number of comets that had no thwart velocity relatively to the sun but that had velocity in the line from comet to sun would be immensely greater than the number of those that had zero velocity in both directions. The former would enter our sphere of visibility equally with the latter, and would have the decided hyperbolic orbits that are never observed. Sir Joseph Larmor, in a letter sent to *The Observatory* in January 1935, made suggestions similar to those

of Professor Perrine. I wrote a reply examining some particular cases: I showed that for a given perihelion distance a certain selected hyperbola was more probable than a parabola; the combination of all hyperbolas would immensely outweigh the parabola, but, in fact, strongly marked hyperbolæ never occur, and eccentricities just above unity have been shown to be due to the action of the large planets.

I drew another argument from the researches on meteors that were recently made by a specially equipped party that recently visited Arizona from Harvard Observatory; they observed meteors from two stations a few miles apart, and made careful calculations on their true paths and velocities. They found that the great majority of the faint meteors had strongly marked hyperbolic orbits; these proved that the meteors came from outside the solar system, and also showed that it was quite an erroneous deduction that bodies coming from outside would show appreciably parabolic paths and not hyperbolic ones.

As regards the origin of the comets of short period by expulsion from the giant planets, I recall that this suggestion was first made by R. A. Proctor; it is necessary with our present knowledge to modify one part of his suggestion. He put the date of the expulsion of the comets as millions of years ago; we now know that rapid disintegration and fading of these comets is going on, so that their whole career cannot extend over

very many centuries. If the giant planets are the parents of comets, such birth must still be going on. The outer regions of these planets are now known to be cold, but there must still be much energy in their deep interiors ; we see this exemplified in such outbursts as the great red spot on Jupiter, the appearances of three brilliant white spots on Saturn within about half a century, and the occasional variability of light of Uranus and Neptune, which probably arose from similar outbursts on these planets. R. A. Proctor showed that the theory that the Leonid meteor swarm was captured by Uranus led to almost insuperable difficulties, hence the date A.D. 126, assigned by Le Verrier to their capture, may be the date of the expulsion of the meteors, including Tempel's comet, from Uranus.

A. C. D. CROMMELIN.

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